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THE COMPOSITION OF INDIAN RAIN AND DEW.

BY

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PART I.

NITROGEN IN THE RAINFALL.

THE amount of ammonia and nitric or nitrous acid, which has been found in the annual rainfall by observers in different parts of the world, has varied within wide limits. One of the most complete statements of the existing knowledge on the subject is found in a recent paper by N. H. J. Miller,[1] from which the following instances may be quoted illustrating extreme quantities. Gray, New Zealand, found ·50lbs. of nitrogen as ammonia per acre per annum in 1884-8, and Marcano and Muntz found 14·03 lb. in Venezuela, 1883-5. Welbel. at Ploty, found ·24 lb. of nitrogen as nitrate and nitrite in 1900-3, whilst Boname found 6·34 lb. in Mauritius, 1895. Most European and American chemists have met with quantities standing mid-way between these extremes. The records maintained at Rothamsted over a period of 15 years, 1889 to 1903, show mean quantities of 2·78 lb. of 'ammonia' nitrogen, and 1·19 lb. of 'nitric' nitrogen per acre per annum, the total being 3·97 lb. The variation in this record has been very small, the largest quantity registered being 4·84 lb. in 1903 and the smallest 3·30 lb. in 1890. No connection is perceptible between these variations and the season or the rainfall.

[1] Amounts of nitrogen as ammonia and as nitric acid, and of chlorine in the rain water collected at Rothamsted by N. H. J. Miller. Journal of Agricultural Science, Vol. I, page 280.

There has been a tendency among writers on agriculture in the East to attribute to tropical rainfall much greater amounts. Atmospheric electrical discharges are specially spoken of as a cause of the formation of more nitric acid in the tropics than in the temperate zones. The evidence of different observers supports this view to only a limited degree. Subjoined are set out the *average* amounts found by different observers in Europe and in the tropics respectively, to which are added the individual data obtained at Madras, *Colombo* and Calcutta.

	NITROGEN. POUNDS PER ACRE.	
	As ammonia.	As nitrate & nitrite.
Mean of European observations	6·52	2·55
Mean of tropical observations	4·26	3·33
Madras: 1888-1893	Total 1·91	
Calcutta: 1891	1·79	1·20
Ceylon: 1898-9[1]	3·65	1·28

The information, then, shows firstly that the European rainfall contains more ammonia and rather less nitrate than some tropical rain; secondly, that the relative proportion of nitric nitrogen is at times somewhat higher in the tropics. On this subject, Miller says, "The one conclusion which may safely be drawn is that tropical rain does not supply to the soil an essentially greater amount of nitrogen than the rain of temperate climates." (*Ibid*, page 287).

A record of the amount of these nitrogen compounds was kept recently for twelve months in the rain at Debra Dun, situated in N. Lat. 30° E. Long. 78° and at Cawnpore, N. Lat. 27° E. Long. 80°, and this record is of interest as additional evidence on the subject.

Samples.—Specimens of the rain water were stored whenever any fell, and once every fortnight (or less) these specimens were mixed together in proportion to the individual falls to which they belonged.

Analytical methods employed.—For the estimation of the *ammonia* 500 cc. were distilled after the addition of 1 drop of concentrated potassium hydrate solution, and the distillate nesslerised. The nessler solution was sufficiently delicate to indicate ·005

[1] M. K. Bamber, Report on Ceylon Tea Soils, Colombo, 1900.

m.gr. of NH_3 *readily*. The *nitrate and nitrite* was determined by Warington's modification of Schloesing's method.

The accompanying statement contains the record.

Dehra Dun.

1904.	Rainfall inches.	NITROGEN. Parts per million. As Ammonia.	Parts per million. As Nitrate and Nitrite.	Pounds per acre. As Ammonia.	Pounds per acre. As Nitrate and Nitrite.	Pounds per acre. Total.
January 15th ...	·51	·49	·129	·059	·016	·075
January 18th	·98	·16	·014	·031	·010	·041
February 4th ...	·06	·82	·728	·011	·010	·021
March 3-4th ...	1·66	·13	·063	·049	·024	·073
March 7th	·38	·33	·127	·029	·011	·040
March 8th ...	·07	·56	·169	·009	·002	·011
March 9th ...	·96	·22	·106	·049	·023	·072
April 8-9th ...	·10	·57	·039	·013	·001	·014
April 14th ...	·10	·11	·890	·003	·020	·023
May 8-15th ...	1·20	·45	·010	·123	·003	·126
May 22-25th	·82	·58	·300	·109	·055	·164
May 31st—June 12th ...	·42	·21	·108	·020	·010	·030
June 20-30th ...	3·35	·20	·147	·152	·112	·264
July 2-13th ...	13·66	·13	·050	·408	·155	·563
July 14-25th	16·11	·11	·080	·402	·293	·695
July 28th—Aug. 13th ...	19·09	·05	·060	·221	·226	·447
August 14-30th ...	18·04	·04	·050	·164	·206	·370
September 1st-17th	5·24	·04	·041	·047	·018	·065
Sept. 18th—Oct. 12th ...	·76	·03	...	·005	...	·005
November 12-16th	·92	·30	·210	·062	·044	·106
Nov. 17th—Dec. 31st ...	2·02	·15	·210	·068	·099	·167
TOTAL ...	86·48	·104	·070	2·037	1·368	3·405

Cawnpore.

1904-05.	Rainfall inches.	NITROGEN. Parts per million. As Ammonia.	NITROGEN. Parts per million. As nitrate and nitrite.	NITROGEN. Pounds per acre. As ammonia.	NITROGEN. Pounds per acre. As nitrate and nitrite.	NITROGEN. Pounds per acre. Total.
May 1-15th ...	·19	·446	·031	·019	·001	·020
May 16-31st ...	·23	·461	·103	·024	·005	·029
June 1-15th	·26	·148	·050	·009	·003	·012
June 16-30th ...	3·77	·247	·067	·211	·058	·269
July 1-15th	5·67	·230	·080	·296	·104	·400
July 16-31st	11·13	·240	·082	·606	·208	·814
August 1-15th	6·74	·200	·059	·306	·091	·397
August 16-31st ..	1·79	·210	·120	·228	·130	·358
September 1-15th	10·77	·080	*Nil*	·191	*Nil*	·191
September 16-30th	2·50	·080		·045	*Nil*	·045
October 1-15th ...	*Nil*	...	......	...	......	...
October 16-31st ...	·03	·550	·470	·004	·003	·007
November 1-15th ...	·41	·910	·384	·084	·035	·119
November 16-30th ...	*Nil*	...	......	...	......	...
December 1-15th	·30	1·020	·220	·069	·015	·084
December 16-31st	·68	·044	·210	·007	·033	·040
January 1-15th ...	·26	1·240	1·100	·073	·006	·079
January 16-31st ...	*Nil*	..	......	...	.....	...
February 1-15th	·11	1·040	·839	·026	·021	·047
February 16-28th	1·36	·830	·178	·256	·055	·311
March 1-15th ...	·16	·780	.. ..	·028	...	·028
March 16-31st ...	·045	probably	contaminated		......	...
April 1-30th	·055	not	analysed	...	......	...
Total ..	49·36	·221	·068	2·482	·768	3·250

Totals for the twelve months' periods.

	Rainfall inches.	NITROGEN.					
		PARTS PER MILLION.		POUNDS PER ACRE.			
		As ammonia.	As nitrate and nitrite.	As ammonia.	As nitrate and nitrite.	Total.	Ratio "NH_3" N to "HNO_3" N.
Dehra Dun	86·48	·104	·070	2·037	1·368	3·405	1 : ·67
Cawnpore	49·36	·221	·068	2·482	·768	3·250	1 : ·31
Compare Rothamsted	27·25	·440	·183	2·712	1·128	3·840	1 : ·42

In addition to the total quantities observed at the two Indian stations, the mean figures of Rothamsted are quoted for comparison.

The following conclusions may be drawn from this record:

(*a*) The total quantity of nitrogen carried by the rain from the atmosphere to the soil at Dehra Dun and Cawnpore is approximately equal to that in the rain at Rothamsted. The largest amount found at the latter station during 15 years was 4·429 lb., and the smallest 3·427 lb. per acre.

(*b*) The ratio of 'ammonia' nitrogen to 'nitric' nitrogen at Rothamsted has been 2·712 : 1·128 = 1 : ·417. So that the *relative* amount of nitric acid in the rain at Dehra Dun was considerably greater than at Rothamsted, whereas at Cawnpore it was somewhat less.

(*c*) A comparison of the actual amounts, however, shows that the rain at the two Indian stations contained less ammonia than at the English one; of nitric acid the Dehra Dun rain contained somewhat more, the Cawnpore rain a good deal less than at Rothamsted.

(*d*) Dehra Dun lies at the foot of the Himalayas and its elevation is about 2,000 ft. above sea-level at the point where the samples were collected. The rainfall is frequently accompanied by heavy thunderstorms, these electrical phenomena being in excess of what is usual in the Indo-Gangetic alluvial area, in which Cawnpore is situated. As the record shows, the amount of nitric acid in the

Dehra rain exceeded considerably that in the Cawnpore rain, and the one year's observations thus add something to the theory that the amount of nitric acid is increased by thunderstorms. But there is no evidence that this factor affects in any material degree the *total* amount of combined nitrogen in the rain. It is true that neither Dehra nor Cawnpore is situated within the tropics, but they are both so nearly so, that if any marked increase in the amount of combined nitrogen was usual in tropical rain, some definite indication of the fact should be present in the rain-waters we are considering.

The data may also be examined for differences in the amount of combined nitrogen in rainfalls of different magnitude. If these substances are washed out of the atmosphere by the falling rain and not obtained principally from that stratum in which the rain is formed, it may be presumed that, on the basis of the law of mass action, the first rain will dissolve out more than the later rain, because the latter will meet with less solute on its passage through the air. The first rain should, therefore, contain more ammonia and nitrate per unit volume. But whether it would contain a greater total amount would depend on the quantity of this "first" part of the fall. It would have been better for this particular purpose if the earlier portion of certain falls had been measured and analysed separately from the later part. This was not done principally because of pressure of other work. However, the data nevertheless provide indirect information on the subject. If the composition of small and large precipitations respectively, received after equal periods of dry weather, are compared, then, assuming that equal amounts of ammonia and nitrate were present in the air, the *concentration* of nitrogen compounds in the lesser fall should be greater than in the larger one; but if the lesser fall is only very small, the *total quantity* of combined nitrogen in it will be less than in the larger one. The data are accordingly arranged below in groups, each group including rainfalls which were preceded by equal intervals of dry weather. Thus we have two falls after less than one dry day, two after three dry days, two after seventeen and nineteen dry days, and two after four weeks of dry weather.

Date.	Interval between falls.	Rainfall inches.	Nitrogen. Parts per million. As ammonia.	As nitrate or nitrite.	Pounds per acre. As ammonia.	As nitrate or nitrite.	Total.
March 8th ..	1 day	·07	·56	·17	·009	·002	·011
March 9th	1 „	·96	·22	·11	·049	·023	·072
January 18th	3 days	·98	·16	·04	·034	·010	·044
March 7th	3 „	·38	·33	·13	·029	·011	·040
February 4th	17 days	·06	·82	·73	·011	·010	·021
January 15th	19 „	·54	·49	·13	·059	·016	·075
March 24th	4 weeks	1·66	·13	·06	·049	·024	·073
April 8-9th	4 „	·40	·57	·04	·013	·001	·014

Examination of the data in this manner reveals very considerable regularity. The fall of March 8th was a very small one, and although rain had fallen on the previous day, this smaller fall contained, per million parts, more ammonia and nitrate than its predecessor. On the following day the fall was heavy (·96″). This contained less nitrogen per million parts. But comparing the total amounts of nitrogen brought into the soil by these two falls, it is evident that the heavier fall carried a much greater quantity with it.

The next group includes the falls of January 18th and March 7th. Both these were received after three dry days, but the former and greater fall contained less ammonia and "nitric" nitrogen per million parts than the smaller fall. In comparing the *total* nitrogen in these two precipitations, it is necessary to note that the lesser was not a very small quantity—·38″, and might be quite sufficient to wash out what ammonia was in the air, if indeed this constituent is mainly obtained in this manner. In that case the *total* nitrogen in these two rainfalls would not exhibit the great difference which is noticeable between the first pair, and as a matter of fact the greater fall contained ·044 lb. per acre and the latter ·040 lb.

The third group includes one fall of ·06″ after seventeen days of dry weather, and one of ·54″ after nineteen dry days. The magnitudes of precipitation are here similar to the first group, and the relations between the concentration on the one hand and total quantity

on the other, are also the same ; the lesser fall possessed the higher concentration of nitrogen compounds, but a much less total weight. Finally, the fourth group is similar in characteristics to the first and third.

In drawing conclusions from the data here discussed, their limited nature has to be remembered. Subject to this reservation it may be said that the evidence points in one direction, and shows that among rainfalls, *succeeding equal periods of dry weather*, the lesser precipitation will possess a greater concentration of nitrogen compounds than the greater. As to the total quantity of these compounds, the lesser fall *may* contain as much as the greater, provided it is not too small, but that falls of ·1" and less do not contain as much as heavier falls. It is important to note the italicised condition. If these rainfalls are merely arranged in order of the magnitude of the rainfall, without reference to the preceding dry weather, no simple generalisations are possible.

The amount of combined nitrogen in rainfalls of different magnitude and after different periods of dry weather was referred to by Lawes and Gilbert in their second paper[1] on the composition of rain water. They say (page 315) "one condition which very largely determines the amount of ammonia present is undoubtedly the quantity of the rainfall ; with increasing quantities of rain the proportion of ammonia always tends to diminish. This is best shown in Table II in which the whole of the daily rainfalls are grouped according to quantity."

PART II.

NITROGEN IN THE DEW.

The rain-gauge at Cawnpore consists of an inverted pyramid of sheet iron, having an area of 1/1,000 part of an acre. It is, in fact, similar to that employed at Rothamsted, excepting that it stands above ground and is of different material. The quantity of dew,

[1] "New determinations of ammonia, chlorine and sulphuric acid in the rain water collected at Rothamsted." By J. B. Lawes, J. H. Gilbert and R. Warington. Journal of the Royal Agricultural Society, England. XIX, ii series, 1883, page 313.

which is very heavy at certain periods of the year in India, was collected on this gauge, and was measured during several months of the "cold weather" of 1904 to 1905; a record of its composition was also kept. There is a danger when collecting such small precipitations, lest any accidental impurities fall on the gauge, and one of the samples contained so much more ammonia than the remainder, that it was discarded as probably contaminated. The record is contained in the subjoined statement.

Period.	Dew in inches.	Nitrogen. Parts per million. As ammonia.	Nitrogen. Parts per million. As nitrate or nitrite.	Nitrogen. Pounds per acre. As ammonia.	Nitrogen. Pounds per acre. As nitrate or nitrite.	Nitrogen. Pounds per acre. Total.
September 1904, 16 30	·011	·85	·51	·002	·001	·003
October .. 1 15	·011	...	·91		·002	·002
Do. .. 16 31	·011	1·6	2·23	·004	·006	·010
November .. 1 15	·016	1·4	1·49	·005	·005	·010
Do. .. 16 30	·027	discarded as unreliable				...
December .. 1 15	·015	1·7	1·09	·006	·004	·010
Do. .. 16 31	·019	1·2	·72	·005	·003	·008
January 1905, 1 15	·020	2·2	2·32	·010	·011	·021
Do. .. 16 31	·015	2·6	1·83	·009	·006	·015
February .. 1 28	·017	2·65	1·12	·010	·015	·025
March .. 1 15	·008	2·5	1·90	·004	·003	·007
Total ...	·170			·055	·056	·111

The available information regarding the quantity and composition of dew is but limited. It was measured at Montpellier, 1893-95,[1] by Hondaille, who determined the deposit which collected on a glass plate of 25 sq. cm. area. Dew was registered in every month of the year, and the mean total amounted to 8·001 mm. (·32 inch) per annum. This record is about twice as great as that at Cawnpore. So far as quantity is concerned it is probable that the method adopted at Cawnpore gives a low result. The whole of the dew deposited during the night does not run off the gauge into the receiver, and what remains on the collecting surface would naturally evaporate again during the following morning. But how great the error here introduced, is not at present known. Nor in the present state of our knowledge of the actual amounts of water which evaporate daily from the soil during the several seasons of the year, is it safe

[1] Ann. Ecole. Nat. Agr., Montpellier, 9. 1895-96; Expt. Stn. Record IX, page 1032.

to express an opinion on the question whether this dew deposit materially affects this evaporation of water from the soil. Of the composition of dew even less appears to be known. Lawes and Gilbert[1] state that "most of the very small deposits represent dew"; this statement refers to the tabulated data on page 316 of their paper, but only one of these deposits is specially noticed, namely, that of September 17, 1881. It measured ·007 inch and contained 5·49 parts of ammonia per million. This appears to have been exceptional, because all the other very small deposits which were analysed, contained quantities of ammonia similar to those found in the Cawnpore dew. Another reference to the composition of dew is found in the Report of the Ploty Agricultural Experiment Station.[2] Welbel there found a mean of 5 m.gr. of ammonia per litre of dew, which is equivalent to 5 parts per million. That dew usually contains more ammonia per unit volume than rain, there seems to be no doubt, and the same applies to the nitrate. Naturally since the total deposit is so small, the total quantity of combined nitrogen thus introduced into the soil is small also. The whole of the Cawnpore deposit for the season contained only ·055 lb. of "ammonia" nitrogen and .056 lb. of "nitric" nitrogen per acre. As a source of combined nitrogen to the soil, dew deposits cannot be considered of great importance. The relatively high proportion of nitrate to ammonia in the Cawnpore dew is very marked. This relationship is fairly regular, and whilst in rain-water the "nitrate" nitrogen is nearly always less, and sometimes very much less than that occurring as ammonia, in the dew the two quantities approach each other more nearly, and in two of the specimens there was a marked excess of "nitrate" over "ammonia" nitrogen. The total quantities of the two for the season are equal, whereas in the Cawnpore rain there was three times as much "ammonia" nitrogen as "nitrate" nitrogen. This circumstance is not what one would expect. It is generally assumed that the ammonia in the atmosphere is derived (away from large towns) from decaying vegetable matter, and there should thus be an excess of

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[1] *Loc. Cit.*, page 315.
[2] Rap. An. Sta. Expt. Agron. Ploty 8 (1902).

ammonia in the atmosphere nearest the earth; the nitric acid on the other hand is attributed to electrical phenomena, much of which occur in the higher atmosphere, and it might be expected that if an excess of nitric acid existed at all, it would be present in the higher strata. Arguing from these premises it might be anticipated that rain, which falls through a so much greater thickness of atmosphere than dew, would tend to contain a higher ratio of nitrate to ammonia, than dew would contain. As has been shown, the exact contrary has been met with. If a conclusion may be drawn from the composition of rain and dew, regarding the relative amounts of ammonia and nitrate or nitrite in the several strata of the atmosphere, the Cawnpore data indicate that there is relatively more nitrate in the lower strata.

THE COMPOSITION OF THE OIL-SEEDS OF INDIA.

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In 1901 and again in 1903, details regarding the chemical composition of Indian food-grains and fodders, as determined in this laboratory, were published in the Agricultural Ledger (1901, No. 10, and, 1903, No. 7). These publications contain some information regarding the oil-seeds of India, but the number of specimens which had then been examined was too limited to admit of a definite opinion being formed regarding the variations which occur in the amount of oil in such seeds in different Provinces.

Since then a large number of specimens of oil-seeds received from various Provinces in India have been examined for oil, and their general composition in other particulars has also been determined. The details are set out in this Memoir.

There is indeed much less accurate information about oil-seeds than about the so-called food-grains. It is probable that all the large crushing firms in Europe and America possess a good knowledge of the amount of oil present in the seeds they deal with, but such information is not usually published. Standard books give but little information; Church's "Food Grains" provides one analysis of one oil-seed, and other authors reproduce odd analyses. American writers are more liberal, but even their exhaustive literature does not, I believe, do justice to the subject. I have referred under the head of the individual seeds to such data as I

have been able to find. A correct knowledge of the amount of oil in these seeds is naturally of value to all parties concerned. To the agriculturist it is of importance to know whether the seed grown by him compares favourably or otherwise with what is grown elsewhere, and one of the chief points brought out by this series of analyses is the variation in the amount of oil which is found in the same seed grown in different Provinces. These differences are not always great, but in some this is the case. To the crusher too, such information must be of not less value, because the amount of oil expressible from any seed varies in a ratio even greater than is indicated by the percentage amount. When an oil-seed is crushed, it may be said that, when using the same mill and a like pressure, the cake will retain approximately the same amount of oil whatever the seed contains. For example, if two samples of an oil-seed, containing respectively 50 % and 40 % of oil, are crushed, and the cake contains 10 % of oil, the nett result is that the one will yield 50 minus $\frac{50 \times 10}{90} = 5 \cdot 5$ or $44 \cdot 5$ parts of oil, while the other will yield 40 minus $\frac{60 \times 10}{90} = 6 \cdot 7$ or $33 \cdot 3$ parts of oil.

Another important subject is touched upon in this Memoir, and about which more precise data will, it is hoped, be obtained in the future. After some of these analyses had been made, specimens of some oil-seeds which had been shown to be richer in oil in one Province than in another, were grown in the latter Province and the seed so obtained analysed. In most cases the result of the experiment indicated that the newly imported seed had suffered deterioration. Unfortunately, however, in all but one such experiment, the initial seed was not analysed, and this fact alone detracts much from the value of the experiments. For it will be obvious that, because certain specimen (say) of sessamum from the Deccan was found to be rich, it does not follow that a precisely equally good sample can be obtained a year or so later; and if this latter is grown in another part of India and the seed analysed, and found to be less rich than the former sample, no proof is provided that depreciation has followed the transfer to the new Province. In one case, however,

the above indicated precautions were taken. Linseed was obtained from several parts of India and grown at Lyallpur in the Punjab. Some of this seed was analysed, as was also the newly-grown crop, and again in the second year the corresponding checks were made. I am permitted by the Director of Agriculture to refer to this experiment and, as the figures show, there seems to be distinctly less oil in the seed grown at Lyallpur than in the original. It is undesirable to draw general deductions from an isolated experiment, and we must hope that either imported oil-seeds into a Province possessing only poor qualities of the seed in question will become rapidly acclimatized and regain their former richness or that means may be found of increasing the amount of oil where the evidence indicates poverty in the seed.

The whole of the individual analyses have been incorporated in the text. These details render the pages a mass of statements, but I hope that those who are interested will find them more useful than if merely average figures had been given.

All the specimens could be readily classed under the genus to which they belong But it was quite unsafe to try to differentiate between varieties, except in the case of some of the Brassicæ from Bengal, which Colonel Prain kindly identified for me in 1900. The specimens of Brassica varieties and of Sessamum included obviously seed of very different size and colour, and it was necessary to group them under corresponding heads. But the other oil-seeds are not so readily divided, and these have, therefore, been merely grouped according to the Province of origin.

Regarding the analytical methods adopted, reference need only be made to that employed for the determination of the oil. When oil-seeds are crushed, they usually assume a very pasty consistence, and it is impossible to ensure the direct disintegration of all the oil-bearing cells. I have, therefore, adopted the plan of first extracting most of the oil from the weighed portion, and then air-drying, re-crushing and re-extracting the residue. After removal of most of the oil, the material is very readily disintegrated in an iron mortar. The procedure is as follows :—The weighed oil-seed, as crushed in a mill (Castor bean was crushed in a mortar), was

extracted with ether in a soxhlet for about two hours; the paper case was taken out and exposed until the ether had vaporized; the oil-flask removed, dried, and weighed as usual. The air-dry and partially exhausted material was then pounded in an iron mortar which was itself placed on a large sheet of clean paper, the object of the latter being to secure any material which might be thrown out of the mortar during the disintegration. Although this precaution was naturally necessary, the experience was that very little material was ejected during the operation. After this pulverization, the material was carefully transferred to the paper case again, and extracted for a further period of 1 hour to 1½ hours. The amount of oil obtained by this second extraction was usually considerable, varying from ·020 grm. to ·150 grm. It may seem at first sight a dangerous process to take weighed material and grind it in a mortar in this manner and that the risk of loss must be great. Apart from it being the only method I could adopt for the purpose, the risk of serious error is not really great. The weight of material employed was about 3 grms. and, supposing that so much as $\frac{1}{10}$ part of this were lost through carelessness (no such loss need ever occur), it would mean a loss of oil not greater than ·015 grms., and this is equal to ·5 per cent. as reckoned on the fresh material. Had this second crushing been neglected, the loss, due to unextracted oil, would often have amounted to ·1 grm. or about 3·33 per cent.

The list of seeds which have been examined includes:—

Arachis hypogæa (Earthnut).
Bassia latifolia (Mowha).
Brassica (Sarson, Toria, Rai).
Carthamus tinctorius (Safflower).
Eruca sativa (Taramira).
Gossypium (Cotton seed).
Guizotia abyssynica (Niger).
Linum usitatissimum (Linseed).
Papaver somniferum (Poppy).
Ricinus communis (Castor bean).
Sessamum indicum (Til, jinjilly).

ARACHIS HYPOGÆA—(*Earthnut*)

	Bombay and Madras only.
Area in acres	500,000
Outturn in tons	200,000

Some information regarding this crop was published in 3ulletins Nos. 28 and 41 of the Madras Agricultural Department, n the latter of which it was shown that the "Mauritius" variety ontained generally 44 to 49 per cent of oil, whereas the "indigenous" ernels contained only 40 to 44 per cent. Since then a number of ther samples have been examined not only from Madras but also from he Bombay Presidency and from Burma, and these are detailed in he subjoined statements. Most of these newer samples have, howver, been recently imported, and although of interest as showing he quality of the newer seed, they do not refer to such extensive reas as the "indigenous" or "deshi" samples. Generally speaking, vhat was observed among the former Madras specimens, holds also or those from the Bombay Presidency, namely, the "indigenous" eed is not so rich in oil as the newly imported. The Burmese pecimens are, however, as rich as the latter. The table shows that he "indigenous" seed contains from 40 to 45 per cent., whilst the imorted varieties contain from 45 to 50 per cent.; a difference almost xactly similar to that previously observed in Madras specimens. These figures refer to the proportion of oil in kernels. The amount resent in the whole seed, including the shell, has been calculated on he assumption that the shell contains no oil, and these figures are lso entered in the statement.

Sample No.	Vernacular Name.	District.	Kernels, Per cent.	Shells, Per cent.	Oil in kernels, Per cent.	Oil in whole seed, Per cent.	Weight of 100 kernels, Grms.
			Madras Presidency.				
714–04	Groundnut ...	North Arcot	74·08	25·92	45·27	33·54	30·4
715–04	Country	Do.	72·95	27·05	43·19	31·51	26·9
716–04	Groundnut	Do.	80·04	19·96	45·95	36·78	39·2
717–04	Mauritius ..	Do. ...	77·94	22·06	48·12	37·50	44·5
1042–04	Do.	Do	78·18	21·82	48·51	37·93	39·1
1198–04	"London" ...	South Arcot	75·40	24·60	49·36	37·22	56·1
811–04	Groundnut ...	Tanjore	80·16	19·84	49·16	39·41	38·7
1–06	Small Japanese ...	Palur	81·18	18·82	48·34	39·24	..
2–06	Big Japanese	Do.	77·22	22·78	48·33	37·32	..

Sample No.	Vernacular name.	District.	Kernels, Per cent.	Shells, Per cent.	Oil in kernels, Per cent.	Oil in whole seed, Per cent.	Weight of 100 kernels, Grms.
		Madras Presidency—(concld.)					
3-06	Tata selected	Palur	76·25	23·75	48·56	37·03	
4-06	Pondicherry	Do.	78·71	21·29	48·75	38·37	
5-06	Virginia ..	Do.	75·24	24·76	48·05	36·15	...
6-06	Spanish Pea-nut ..	Do. ...	78·07	21·93	46·72	36·47	..
7-06	Barbados ..	Do. ..	70·96	29·04	46·14	32·74	...
8-06	Mauritius, Ceylon ...	Do. ...	76·90	23·10	49·32	37·93	...
9-06	Tanjore ..	Do. ..	80·58	19·42	49·37	39·78	.
10-06	Madagascar ..	Do. .	75·40	24·60	48·28	36·40	...
11-06	Local Mauritius ...	Do. ...	79·55	20·45	49·21	39·15	...
12-06	Native .	Do. ..	73·94	26·06	44·88	33·18	...
13-04	Barbados, Ceylon ..	Do. ...	77·55	22·45	44·90	34·82	...
14-06	Mauritius do.	Do. ...	78·22	21·78	47·78	37·37	...
15-06	Mauritius from Mauritius ...	Do. ..	76·66	23·34	48·65	37·30	...

Average of 1900 samples :—

	Kernels. Per cent.	Shells. Per cent.	Oil in kernels. Per cent.
8 Specimens of "indigenous" seed	74·8	25·2	41·82
10 Do. "Mauritius" seed ...	76·8	23·2	46·09

Sample No	Vernacular Name.	District.	Kernels. Per cent.	Shells. Per cent.	Oil in kernels. Per cent.	Oil in whole seed. Per cent.	Weight of 100 kernels. Grms.
		Bombay Presidency.					
68-06	Japan, big ..	Sind ..			48·70		
69-06	Do. small...	Do. ...			49·51		...
70-06	Java .	Do. ...	...		44·74		..
71-06	Mozambique	Do. ...	...		49·76		
72-06	Pondicherry	Do. ...			49·23		...
73-06	Senegal ...	Do. ...	...		48·46	...	...
74-06	Spanish Pea-nut ...	Do. ...			48·08		...
75-06	Surti, Deshi (country) ..	Do. ...		...	41·62	...	...
76-06	Virginia ...	Do. ...		...	47·10	...	...
463-04	Japanese, big	Surat ..	75·9	24·1	45·65	34·74	75·0
464-04	Do. small	Do. ...	80·89	19·11	49·75	40·24	52·0
465-04	Pondicherry	Do. ..	72·48	27·52	43·27	31·37	39·0
466-04	Spanish .	Do. ...	79·22	20·78	48·87	38·72	46·0
467-04	Virginia .	Do.	76·85	23·15	47·33	36·37	68·0
468-04	Deshi, country	Do. ...	72·41	27·59	45·27	32·78	41·0
214-06	Virginia ...	Do. ...	...	..	47·21	...	..
215-06	Pondicherry	Do. ...	...	...	48·31	...	..
216-06	J apanese, big	Do. ...	...		47·68		..
217-06	Do. small	Do. ...	...	..	50·40	...	..
218-06	Spanish Pea-nut ...	Do. ...	...	...	51·43	...	...

Sample No.		Vernacular name.	District.	Kernels. Per cent.	Shells. Per cent.	Oil in Kernels. Per cent.	Oil in whole seed. Per cent.	Weight of 100 kernels. Grms.
			Bombay Presidency—(concld.)					
219	06	Local ...	Surat		...	47·43		
1177	04	Groundnut	Belgaum			41·49		27·8
1181	04	Do.	Do.	77·32	22·68	42·96	33·22	30·9
1185	04	Do.	Do.			42·52		31·0
251	04	Do. ...	Poona	76·14	23·56	43·32		33·6
254	04	Do.	Ahmednagar			44·86		41·3
262	04	Do.	Sholapur		..	40·57		24·4
325	04	Do.	Satara			45·65		38·6
			Burma					
55	04	Groundnut	Meiktila	75·19	24·81	46·14	34·69	49·4
655	04	Do. ...	Prome	78·45	21·55	50·21	39·39	43·2
747	04	Mayaype	Minbu	72·74	27·26	48·58	35·34	36·7
1271	04	Groundnut	Hasmongkham	67·77	32·23	44·26	30·00	33·9
1288	04	Myipa	Central Burmah.	74·78	25·22	46·36	34·67	38·3
1294	04	Do. ...	Kengtung	65·34	34·66	46·06	30·10	31·5

Average composition (*Kernels only*) :

	Bombay	Burma	Madras.
Moisture	6·83	7·26	6·28
Oil	45·36	47·26	46·34
Albuminoids	26·20	26·09	25·59
Soluble Carbohydrates ...	16·80	14·72	17·42
Woody fibre	2·09	2·05	1·95
Soluble mineral matter	2·63	2·57	2·37
Sand	·09	·05	·05
	100·00	100·00	100·00
Total Nitrogen	4·33	4·24	4·32
Albuminoid Nitrogen ..	4·19	4·17	4·09

Average proportion of shells and kernels :—

	Bombay	Burma	Madras.
Kernels, per cent	76·44	72·38	76·14
Shells, per cent	23·56	27·62	23·86

Composition of whole seed calculated on the assumption that the shells are entirely indigestible "woody fibre."

	Bombay	Burma	Madras.
Moisture ..	5·23	5·26	4·78
Oil	34·64	34·20	35·28
Albuminoids ..	20·05	18·90	19·50
Soluble Carbohydrates	12·87	10·63	13·25
Woody fibre	25·16	29·11	25·34
Soluble mineral matter	2·01	1·86	1·81
Sand	·07	·04	·04
	100·00	100·00	100·00
Total Nitrogen	3·32	3·07	3·29
Albuminoid Nitrogen ...	3·20	3·02	3·12

BASSIA LATIFOLIA—*Moocha seed (Kernels).*

The number of specimens of this seed which has been examined is too small to admit of any general deductions. The analyses are inserted, however, because of the very limited information on the subject which is available.

Sample No.	Local Name.	District.	Oil. Per cent.
	Central Provinces.		
124–04	......	Nimar	48·13
181–04	Gulli	Seoni	36·01
	United Provinces.		
1070–04	Mahua	Sultanpur	48·15
1071–04	Do.	Do.	46·95
1072–04	Do.	Do.	47·11
1073–04	Do.	Do.	48·67
1074–04	Do.	Do.	49·04
1075–04	Do.	Do.	46·60
1076–04	Do.	Do.	49·19
1077–04	Do.	Do.	49·19

BRASSICA.

	Area in British India.	Average yield.
	Acres.	Tons.
Grown as single crop ...	3,500,000	850,000
Grown as mixed crop ...	2,500,000	

There are few crops in India which include such a variety of seed as the Brassicæ. The individual crops appear to be largely mixtures, and it would have been an advantage if specimens of the pure varieties could have been examined in addition to the specimens of local production, but no opportunity occurred for this. However, since some of the most representative samples, as obtained from different districts, were similar to one another, it was possible to classify them in a great measure. The specimens fall under the following chief groups: "Yellow sarson" (probably Brassica campestris), twenty-five specimens chiefly from the United Provinces; and red or slaty coloured seed of various shapes and sizes, sixty-two specimens. The latter have been sub-divided according to colour and size into Sarshaf or Toria from the Punjab, a slaty brown or dark red seed weighing

from[1] ·2 to ·4 grm. per 100 seeds, and "Sarson kali" from the United Provinces similar in size to "Sarshaf," but redder coloured; and secondly, the "Rai" of the Punjab, a much smaller seed than the foregoing, weighing from ·07 to ·15 grm. per 100 seeds. The other samples have been brought into this classification as far as possible, though characterized by difference in shape, colour and weight.

Yellow Sarson.—The fifteen specimens from the United Provinces were uniform in colour and comparatively so in other respects. Their weight varied from ·41 to ·71 grm. per 100 seeds, and if one or two extremes are excluded, the variation is from about ·48 to ·68 grm. It is the heaviest of the varieties of Brassica. The amount of oil varied from 44 to 49 per cent. The Assam specimens were distinctly smaller, weighed ·3 to ·4 grm. per 100, and contained apparently less oil. The specimens from other Provinces were too few in number to admit of general deductions, but they do not appear to contain so much oil as the United Provinces specimens.

"*Sarshaf*" and "*Toria*" from the Punjab are seeds which are characterized by some irregularity in colour and shape. Whether the crop throughout the Province is a mixture, or whether these characteristics are common to the variety, is uncertain. Otherwise the seed is fairly uniform. The weight varies from ·21 to ·41, or excluding extremes ·25 to ·35. It contains generally from 37 to 45 per cent. of oil, *i.e.*, very appreciably less than the yellow seed. Specimens of "Kali Sarson" from the United Provinces were somewhat larger, and distinctly redder in colour. These twelve specimens weighed from ·3 to ·5 and contained from 39 to 46 per cent. of oil, *i.e.*, much about the same as Punjab Sarshaf. From Partabgarh, however, two specimens of a much larger seed were received; they weighed ·66 grm. and contained 46 per cent. of oil. The remaining twenty-five specimens which I have classed under this group varied much more in weight, colour and percentage of oil; some of them

[1] In order to abbreviate this expression of the weight of seeds the mere figures are frequently used in the text by themselves, such as "weight of seeds ·2 to ·4" would mean ·2 to ·4 grm. per 100 seeds.

contained only 33 per cent. oil. The "Toria" from Sind was similar in appearance to that of the Punjab.

Thirdly, the samples of the Punjab "Rai." with two of "Desi-rai" from the United Provinces, have been classed together, because they are distinctly smaller than the foregoing, red in colour and contained less oil; their weight varied from ·07 to ·15, and the percentage of oil varied from 27 to 37.

Among the few references by foreign writers to the amount of oil in Brassica, Armsby mentions 55 per cent. as the highest, 36 per cent. as the lowest and 42·5 per cent. as the mean of a number of specimens.

YELLOW SARSON.

Sample No.	Local Name.	District.	Oil. Per cent.	Weight of 100 seeds. Grms.
		United Provinces.		
664–04	Sarson–Zard	Cawnpore	48·64	·483
665–04	Do.	Do.	47·91	·495
935–04	Do.	Do.	45·47	·603
943–04	Do.	Do.	45·73	·603
939–04	Do.	Unao	48·52	·504
945–04	Do.	Do.	48·16	·522
937–04	Do.	Partabgarh	49·23	·413
940–04	Do.	Do.	48·75	·604
941–04	Do.	Do.	46·33	·640
944–04	Do.	Do.	48·92	·404
936–04	Do.	Do.	46·04	·632
942–04	Do.	Do.	43·84	·640
946–04	Do.	Do	44·60	·630
923–04	Do.	Meerut	45·67	·673
938–04	Do.	Do.	45·41	·710
		Assam.		
405–04	"White" Mustard	Sylhet	45·10	·368
703–04	"Yellow" Mustard	Kamrup	42·61	·315
704–04	Do.	Do.	36·88	·238
238–04	Obhota Sariah	Jorhat	43·68	·399
237–04	Baga do.	Do.	42·68	·326
		Bombay Presidency.		
401–04	Rape	Nadiad	35·72	·439
454–04	Sarson	Surat	43·00	·531
		Central Provinces.		
158–04	Sarson	Raipur	46·75	·466
918–04	Rapeseed—"Yellow"	Bilaspur	47·21	·296
		Punjab.		
80–04	Sarshaf	Kangra	43·88	·489

SARSON—(*other sorts*).

Sample No.	Local Name.	District.	Oil, Per cent.	Weight of 100 seeds, Grms.	
		Punjab.			
89—04	Sarshaf	Muzaffargarh	45·49	·283	Slaty brown and dark red seed.
19—04	Toria	Chenab Canal	44·94	·327	
85—06	Sarshaf	Kangra	44·33	·250	
96—04	Do.	Ambala	42·45	·297	
14—04	Do.	Gurgaon	41·95	·415	
68—04	Toria	Montgomery	41·37	·268	
20—04	Sarshaf	Chenab Canal	40·66	·339	
143—04	Toria	Gujrat	40·33	·288	
138—04	Sarshaf	Sialkot	40·04	·212	
137—04	Toria	Do.	39·46	·236	
141—04	Sarshaf	Gujrat	39·45	·349	
152—04	Do.	Rawalpindi	38·53	·273	
95—04	Toria	Ambala	37·96	·292	
9—04	Sarshaf	Hissar	37·88	·344	
88—04	Toria	Muzaffargarh	36·89	·287	
		United Provinces.			
666—04	Sarson Kali	Cawnpore	39·86	·271	Seed similar in size to Punjab Sarshaf, but redder in colour.
667—04	Do.	Do.	39·03	·309	
950—04	Do.	Do.	39·05	·319	
951—04	Do.	Do.	39·35	·314	
924—04	Do.	Unao	40·64	·366	
919—04	Do.	Do.	40·44	·383	
948—04	Do.	Aligarh	46·73	·478	
952—04	Do.	Do.	46·37	·528	
947—04	Do.	Meerut	40·70	·398	
953—04	Do.	Do.	40·54	·413	
954—04	Do.	Aligarh	41·07	·359	
957—04	Do.	Do.	40·94	·362	
955—04	Sarson Red	Partabgarh	46·16	·665	
956—04	Do.	Do.	45·53	·660	
958—04	Rai Siah	Do.	41·80	·368	
959—04	Do.	Do.	41·32	·315	
		Central Provinces.			
197—04	Mustard	Balaghat	46·09	·292	Large, dark red, round seed.
105—04	Sarson	Jabalpur	45·61	·304	
159—04	Rai	Raipur	44·24	·285	
170—04	Mustard	Sambalpur	43·43	·340	
106—04	Rai	Jabalpur	42·16	·213	Irregularly shaped dark red seed.
292—04	Do.	Mandla	40·16	·231	
116—04	Mustard	Hoshangabad	36·34	·276	
133—04	Do.	Damoh	36·16	·229	
219—04	Do.	Chanda	34·36	·241	
221—04	Do.	Do.	32·45	·208	
200—04	Do.	Narsingpur	38·22	·156	Dark red small round seed.
126—04	Do.	Nimar	34·96	·153	
77—04	Rai	Seoni	33·08	·142	
132—04	Jagni or Sarson	Damoh	40·57	·272	
917—04	Rapeseed—"Red"	Bilaspur	45·62	·313	
		Assam.			
239—04	Ranga Sariah	Jorhat	41·11	·327	
240—04	Kala do.	Do.	35·93	·364	
407—04	Mustard	Sylhet	41·50	·286	
705—04	Black Mustard	Kamrup	35·65	·290	
		Bombay Presidency.			
901—04	Toria	Jamrao Canal, Sind	39·23	·298	
902—04	Do.	Do. do.	41·75	345	

SARSON—(*other sorts*)—contd.

Sample No.	Local Name.	District.	Oil. Per cent.	Weight of 100 seeds. Grms.
		Bengal.		
175–04	Mustard	...	40·60	·300
		Burmah.		
565–04	Monyin	Prome ...	45·59	·314
		RAI.		
		Punjab.		
156–04	Rai ...	Rawalpindi	37·48	·152 Colour similar to Sarshaf, but seed smaller.
147–04	Do. ...	Gujrat	36·78	·122
82–04	Do.	Muzaffargarh ...	35·82	·156
99–04	Do.	Ambala	31·27	·158
81–04	Do. ...	Kangra ...	35·28	·090
17–04	Do. ...	Gurgaon ...	34·13	·113
12–04	Do.	Hissar ...	29·79	·090
23–04	Do. ...	Chenab Canal ...	29·73	·084
71–04	Do. ...	Montgomery ...	28·61	·077
141–04	Do. ...	Sialkot	27·21	·081
		United Provinces.		
925–04	Desi-Rai ...	Aligarh	36·05	·176
960–04	Do. ...	Do. ...	35·62	·168

Bengal.

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BRASSICA JUNCEA, H. f. & T.

Syn.: Sinapis juncea. Sinapis ramosa, Roxb.

English: Indian Mustard.

Vern.: Asl-rai.

Sample No.	Local Name.	District.	Oil. Per cent.
380–00	"Kajli Sarsa" ...	24-Parganas ...	40·22
385–00	Lalki tori	Dumraon ...	39·46
518–00	Rai	Nadia	32·51
520–00	Do.	Arraria ...	40·84
	BRASSICA NAPUS, Linn.; var. Dichotoma. English: Indian Rape. Vern.: Tori, Lotni, Moghi.		
388–00	Latni	Hazaribagh ...	38·21
496–00	Lotni	Ranchi ...	40·00
519–00	Jehanabad	Bengal	40·18
	BRASSICA CAMPESTRIS, Linn.; var. Sarson, Prain. English: Indian Colza. Vern.: Sarson, Sweti.		
383–00	Piarka tori	Dumraon	41·51
384–00	Lalka tora	Do.	39·73
386–00	Piarki tori ...	Do. ...	41·42
389–00	Seta Sarisa	Rangpur ...	42·62
521–00	... ...	Arrah	43·92

The following illustrates the average composition of the seed :

	Sarshaf or Toria, Punjab.	Rai, Punjab.	Rai, Central Provinces.	Yellow Sarson, United Provinces.	Yellow Sarson, United Provinces.	Yellow Sarson, Assam.	Sarson, other sorts, United Provinces.
Moisture	6·98	7·06	6·04	5·16	6·12	7·01	5·96
Oil	39·76	30·28	38·63	45·54	47·42	41·59	40·45
Albuminoids	17·26	19·88	18·90	15·96	17·29	18·54	18·10
Soluble Carbohydrates	25·63	30·69	27·64	24·06	21·88	23·51	26·55
Woody fibre	5·37	5·92	4·90	4·39	3·59	3·84	4·74
Soluble mineral matter	4·11	4·99	3·01	3·75	3·50	4·21	3·86
Sand	·89	1·18	·79	1·04	·19	1·30	·31
	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Total Nitrogen	3·35	3·74	3·74	3·51	2·97	3·23	3·39
Albuminoid Nitrogen	2·76	3·18	3·01	2·55	2·77	2·97	2·89

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Bengal.

	Brassica juncea, 4 samples, average.	Brassica napus, 3 samples, average.	Brassica campestris, 5 samples, average.
Moisture	7·68	6·69	7·21
Oil ...	38·26	39·46	41·82
Albuminoids	19·11	18·29	20·09
Soluble Carbohydrates	24·10	23·18	22·01
Woody fibre	5·48	5·24	4·47
Soluble mineral matter	4·29	4·19	3·96
Sand and Silica ...	1·06	2·84	·39
	100·00	100·00	100·00
Total Nitrogen	3·31	3·17	3·47
Albuminoid Nitrogen	3·06	2·93	3·21

CARTHAMUS TINCTORIUS (*Safflower seed*).

The accompanying statement exhibits the proportion of oil in thirty samples of *Safflower* seed.

The variation in the amount of oil is not great. The one sample from Bengal contains only 22·47 per cent., but it seemed to be discoloured somewhat; and one sample from Bellary and one from Chhindwara contained less than 24 per cent. But the remainder contained from 26 up to about 32 per cent. The Central Provinces samples contained a little earth, but all the others were clean. Any such earth was of course excluded from the portions analysed.

Sample No.	District.	Oil. Per cent.	Weight of 100 seeds. Grms.
	Central Provinces.		
79–04	Seoni	30·49	6·774
163–04	Raipur	26·57	3·405
403–04	Balaghat	26·42	5·264
578–04	Chhindwara ...	23·54	5·953
707–04	Betul	31·82	6·311
914–04	Bilaspur	29·93	4·379
	Bombay Presidency.		
241–04	Nasik	31·23	4·963
248–04	Poona	30·03	4·910
252–04	Ahmednagar ...	31·02	4·440
261–04	Sholapur	29·56	4·931
272–04	Dharwar ..	30·16	4·986
324–04	Satara	32·23	5·218
400–04	Nadiad	28·79	4·210
455–04	Surat . ..	29·51	5·516
471–06	Poona	31·27	5·028
	Madras Presidency.		
404–04	Anantapur .	31·05	3·890
500–04	Gooty	33·55	4·153
567–04	Nandyal	30·63	3·885
814–04	Kurnool	29·96	4·622
815–04	Kurnool	30·64	4·540
1034–04	Gooty .. .	28·69	3·916
1047–04	Bellary	26·60	2·973
1052–04	Do.	23·88	4·559
	United Provinces.		
672–04	Cawnpore	28·11	3·348
673–04	Do. ...	29·00	3·670
927–04	Do.	27·94	4·600
968–04	Partabgarh... ...	29·49	4·204
969–04	Cawnpore	28·40	4·936
970–04	Partabgarh...	29·78	4·269
	Bengal.		
477–04	....	22·47	3·209

AVERAGE COMPOSITION.

	Central Provinces.	Bombay Presidency.	Madras Presidency.	United Provinces.
Moisture	5·31	5·22	6·22	6·16
Oil	27·13	29·85	29·83	27·45
Albuminoids	9·38	12·06	12·66	11·50
Soluble Carbohydrates ...	27·36	24·91	23·75	25·14
Woody fibre	27·43	25·94	24·46	27·42
Soluble mineral matter .	2·48	1·97	2·48	2·23
Sand	·91	·05	·60	·10
	100·00	100·00	100·00	100·00
Total Nitrogen	1·64	2·37	2·16	2·07
Albuminoid Nitrogen ..	1·56	1·93	2·07	1·84

ERUCA SATIVA.—(*Vern.: Taramira.*)

Some specimens of this were received from the Punjab and the United Provinces, together with one sample from Bengal. As will be seen from an inspection of the figures, the specimens from the United Provinces contain appreciably more oil than those from the Punjab, and since this difference is regular, it may be presumed to be a general one. One cannot of course make deductions from the one Bengal specimen. The samples were fairly free from earthy materials.

Sample No.	Local Name.	District.	Oil, Per cent.	Weight of 100 seeds, Grms.
		Punjab.		
11–04	Taramira	Hissar	31·96	·274
16–04	Ditto	Gurgaon	31·77	·321
22–04	Ditto	Chenab Canal	25·40	·248
70–04	Ditto	Montgomery	27·33	·227
91–04	Ditto	Muzaffergarh	30·08	·285
98–04	Ditto	Ambala	32·82	·408
140–04	Ditto	Sialkot	28·12	·206
146–04	Ditto	Gujrat	32·57	·326
151–04	Ditto	Rawalpindi	30·24	·169
		Bengal.		
588–04	Taramira	[illegible]	33·05	·264
		United Provinces.		
928–04	Duan or Taramira	Partabgarh	31·72	·345
961–04	Ditto	Cawnpore	36·32	·393
962–04	Ditto	Partabgarh	31·30	·336
963–04	Ditto	Aligarh	36·71	·434
668–04	Ditto	Cawnpore	33·65	·258
669–04	Ditto	Do.	31·39	·251
964–04	Ditto	Meerut	33·69	·448
965–04	Ditto	Do.	31·40	·507
966–04	Ditto	Aligarh	36·57	·411
967–04	Ditto	Cawnpore	36·16	·442

AVERAGE COMPOSITION.

	Punjab.	United Provinces.
Moisture	6·81	6·69
Oil	28·99	33·33
Albuminoids	22·82	21·56
Soluble Carbohydrates	29·51	28·63
Woody fibre	5·41	5·19
Soluble mineral matter	4·62	3·92
Sand	1·84	·68
	100·00	100·00
Total Nitrogen	4·21	4·19
Albuminoid Nitrogen	3·65	3·45

GOSSYPIUM—(*Cotton-seed*).

Average area in acres ...	20,000,000
Approximate outturn in tons ...	1,200,000

Detailed information regarding the amount of oil in Indian cotton-seed was published in Agricultural Ledger No. 9 of 1903, and a summary only is inserted here.

	Oil in whole seed. Per cent.
26 specimens from Madras Presidency ...	17·41
18 " Bombay " ...	17·66
15 " Central Provinces ...	19·65
15 " United " ...	19·89

The variation in individual samples was only small, being from 15 to 21 in extreme cases. The amount of oil contained in Indian seed is then very much less than in American, which contains upwards of 30 per cent. The Indian seed is also smaller. Specimens of American weighed 12 to 18 grammes per 100 seeds, and Egyptian 10 to 11 grammes, whilst Indian seed weighed only 5 to 7 grammes.

GUIZOTIA ABYSSYNICA—(*Niger*).

The specimens of this seed were characterized by very considerable uniformity in colour, size of seed and amount of oil.

Sample No.	Local Name.	District.	Oil. Per cent.	Weight of 100 seeds. Grms.
		Central Provinces.		
62—04	Ramtilli	Sagor	38·85	·303
78—04	Jagni	Seoni	39·06	·288
104—04	Ramtilli	Jabalpur	38·78	·268
122—04	Do.	Nimar	41·71	·298
131—04	Do. or Jagni	Damoh	39·03	·341
200—04	Do. or Sarsoa	Balaghat	37·30	·204
207—04	Jagni or Ramtilla	Narsingpur	36·17	·244
294—04	Do.	Mandla	36·75	·274
575—04	Jagni	Chhindwara	36·94	·269
710—04	Do.	Betul	38·57	·215
919—04	Ramtilla	Bilaspur	39·96	·360
		Bombay Presidency.		
244—04	Niger	Nasik	39·90	·334
250—04	Do.	Poona	38·28	·373
255—04	Do.	Ahmednagar	41·40	·328
260—04	Do.	Sholapur	42·00	·409
263—04	Do.	Kolaba	39·29	·325
270—04	Do.	Dharwar	40·83	·418
327—04	Do.	Satara	40·56	·370
413—04	Do.	Thana	41·77	·410
456—04	Kharsani	Surat	39·29	·417
473—04	Niger	Poona	43·27	·416

Sample No.	Local Name.	District.	Oil. Per cent.	Weight of 100 seeds. Grms.
		Madras Presidency.		
448—04	Niger ...	Salem	41·47	·422
533—04	Do.	Berhampur ...	37·88	·337
740—04	Valesellu ...	Ganjam	37·47	·311
810—04	Niger	Do.	40·40	·366
1036—04	Do.	Salem ...	39·45	·394
1046—04	Gronuvulu ...	Bellary	41·87	·464
1051—04	Do. ...	Do.	41·89	·463
1063—04	Niger	Hasur, Salem	36·37	·370
1062—04	Do.	Do. Do. ...	36·29	·348
		Bengal.		
494—04	Niger ...	...	40·33	·378

AVERAGE COMPOSITION.

	Central Provinces.	Bombay Presidency.	Madras Presidency.
Moisture	5·53	5·33	6·03
Oil ...	38·53	39·95	39·40
Albuminoids	18·54	19·02	17·94
Soluble Carbohydrates ...	19·08	17·99	19·32
Woody fibre ...	12·31	12·54	11·94
Soluble mineral matter	5·29	4·64	5·18
Sand ...	·72	·53	·19
	100·00	100·00	100·00
Total Nitrogen	3·07	3·26	3·02
Albuminoid Nitrogen	2·97	3·04	2·87

LINUM USITATISSIMUM (*Linseed*).

	Area in British India. Acres.	Yield. Tons.
Grown as single crop ...	3,000,000	300,000
Grown as mixed crop ...	500,000	

The accompanying statement exhibits the percentage of oil in fifty-four samples of *Linseed* which have been received from the several Provinces named. There is, on the whole, remarkably little variation in the proportion of oil. The Central Provinces and the United Provinces samples contain up to 44 per cent., and some of the Punjab samples fall as low as 37 per cent. (one as low as 35·6) but these are the extremes

Most of them were brown linseed. One sample from Nimar and one from Cawnpore were practically wholly white ; and samples from Surat, Wardha, Hoshangabad, Narsingpur and Sambalpur contained more or less white linseed. All these contained high

proportions of oil, but at the same time equally high proportions were contained by pure brown linseed, so that there is no evidence to show that the one contains generally more oil than the other.

Some of the seed was distinctly small, such as that from Kangra and Rawalpindi, but there is not much evidence that any connection exists between the size of the seed and the amount of oil. Some of the larger Central Provinces varieties weighing ·8 or ·9 gramme per 100 seeds contain only as much oil as No. 920—04 from Bilaspur which weighed only ·55 gramme. At the same time it may be said that all the samples of bold seeds, weighing ·7 gramme or more per 100, contain high percentages of oil.

The only samples which were not clean were those from the Punjab. These, excepting that from the Kangra district, were mixtures of large and small linseed together with rape, wheat, etc., and straw, and they compared very badly with the general purity of the samples from other parts of India.

Sample No.	District.	Colour.	Oil. Per cent.	Weight of 100 seeds. Grms.
		Punjab.		
10—04	Hissar	Brown	40·40	·452
15—04	Gurgaon	Do.	41·50	·560
21—04	Chenab Canal	Do.	41·91	·609
69—04	Montgomery	Do.	37·91	·459
83—04	Kangra	Do.	38·61	·286
90—04	Muzaffargarh	Do.	35·60	·581
97—04	Ambala	Do.	37·59	·553
139—04	Sialkot	Do.	38·02	·614
145—04	Gujrat	Do.	39·41	·630
153—04	Rawalpindi	Do.	37·14	·395
		Central Provinces.		
63—04	Saugor	Brown	42·43	·967
76—04	Seoni	Do.	43·35	·710
103—04	Jabalpur	Do.	42·93	·721
115—04	Hoshangabad	½ White	40·64	1·029
123—04	Nimar	White	43·64	·757
128—04	Damoh	Brown	44·20	·890
160—04	Raipur	Do.	39·89	·520
176—04	Sambalpur	¼ White	42·09	·724
194—04	Balaghat	Brown	42·90	·544
206—04	Narsingpur	¼ White	42·77	·854
221—04	Chanda	Brown	40·74	·815
222—04	Do.	Do.	41·88	·752
223—04	Do.	Do.	43·15	·788
293—04	Mandla	Do.	40·17	·523
542—04	Hoshangabad	"Khakhri" ½ white	43·93	·934
543—04	Do.	"Lal," brown	42·81	·861
848—04	Wardha	White	43·80	·800
549—04	Do.	"Red," brown	36·47	·818

Sample No.	District.	Colour.	Oil. Per cent.	Weight of 100 seeds. Grms.
		Central Provinces (concld.)		
572—04	Chhindwara	"Red," brown	43·02	·831
711—04	Betul	Brown	41·73	·773
929—04	Bilaspur	..	42·05	·652
		Bombay Presidency.		
245—04	Nasik	Brown	43·63	·872
246—04	Poona ...	..	42·05	·771
258—04	Sholapur	..	44·45	·835
271—04	Dharwar	.. ...	41·23	·669
323—04	Satara	..	42·85	·731
453—04	Surat, White	..	43·40	·888
472—04	Poona.	.. ...	41·75	·746
		Madras Presidency.		
568—04	Karnool	Brown	41·49	·696
812—04	Ditto	..	41·35	·687
813—04	Ditto	.. ...	41·71	·703
1048—04	Bellary	..	40·36	·660
1053—04	Do.	..	40·72	·682
		United Provinces.		
674—04	Cawnpore	... Brown	42·87	·558
675—04	Ditto	"Red," brown	42·19	·537
928—04	Partabgarh	... White	44·19	·613
929—04	Cawnpore	"Red," brown	44·55	·923
971—04	Partabgarh	..	42·30	·619
972—04	Cawnpore	..	42·28	·828
973—04	Ditto	..	41·70	·803
974—04	Unao	..	41·41	·775
975—04	Do.	..	41·77	·743
		Bengal.		
197—04		Brown	41·40	·516
		Assam.		
406—04	Sylhet	Brown	42·06	·521

Among other authorities, Armsby[1] quotes 21·7% of oil as a minimum for flax seed and 35·6% as a maximum. Smetham[2] quotes the following:

	Oil. Per cent.
Bombay Linseed	38·21
Morschanski ...	30·81
Black Sea	30·78
Riga ...	31·19
St. Petersburg ...	35·31
Alexandria ...	35·73

The Indian specimens that I have examined are thus richer on the whole than the produce of other countries.

[1] Manual of Cattle Feeding, p. 183.
[2] Variations in the composition and feeding value of purchased feeding stuffs, p. 7.

AVERAGE COMPOSITION.

	Punjab.	Central Provinces.	Bombay Presidency.	Madras Presidency.
Moisture	7·60	6·73	6·81	6·72
Oil	38·27	41·36	40·71	40·12
Albuminoids	14·86	18·50	19·74	19·07
Soluble Carbohydrates	29·17	24·62	24·23	24·94
Woody fibre	5·74	4·80	5·01	5·35
Soluble mineral matter	3·72	3·22	2·96	3·26
Sand	·64	·77	·54	·54
	100·00	100·00	100·00	100·00
Total Nitrogen	2·55	3·05	3·28	3·14
Albuminoid Nitrogen	2·38	2·97	3·12	3·05

PAPAVER SOMNIFERUM—(*Poppy seed*).

The same remark must be made in relation to this seed as applied to Bassia latifolia The number of specimens is so small as to preclude any general conclusions regarding the amount of oil in this seed in different parts of India. The variations in the specimens examined were, however, very small.

Sample No.	District.	Oil. Per cent.	Weight of 100 seeds. Grms.
	United Provinces.		
670–04	Cawnpore ...	47·90	·031
671–04	Do. ...	47·58	·034
930–04	Do. ...	47·60	·037
976–04	Unao ...	47·32	·036
977–04	Do. ...	16·35	·035
978–04	Partabgarh	48·33	·033
979–04	Do. ...	48·66	·033
980–04	Cawnpore ...	48·20	·038
	Bengal.		
496–04	.....	48·13	·034
	Burma.		
573–04	....	44·82	·035

RICINUS COMMUNIS—(*Castor Bean*).

Numerous specimens of this seed have been examined. The list includes thirty-nine from Madras, thirteen from Bombay, twenty from the United Provinces and twenty-five from the Central Provinces. The oil was determined in the kernel; the percentage in the whole seed was calculated from this figure after

allowing for the shell. With very few exceptions, the oil varies in kernels from 60 to 70 per cent., and this variation may be considered small. As is well known, the size of this seed varies very much indeed, and this is shown by the last column of the statement. The weight per 100 seeds is as low as 9 grms. in one case, and as high as 59·7 in another—a difference far greater than occurs in other oil-seeds, and is indeed quite remarkable. The percentage of shell is, however, much more constant. Moreover, a high proportion of shell is not coincident with a small seed, and presumably the thickness of the shell increases slightly with the size of the seed.

Sample No.	Vernacular Name.	District.	Kernels, Per cent.	Shells, Per cent.	Oil in kernels, Per cent.	Oil in whole seed, Per cent.	Weight of 100 seeds, Grms.
		Madras Presidency.					
140–03	Large seed	Vizianagram	74·24	25·76	66·88		
150–03	Small do.	Godavery	69·23	30·77	67·00		
1230–04	Castor seed	Do.	69·95	30·05	67·07	46·91	22·3
1231–04	Do.	Do.	71·42	28·58	67·05	47·88	21·8
1317–04	Do.	Do.	70·79	29·21	67·42	47·51	22·6
421–04	Do.	Kistna	70·61	29·39	67·81	47·88	21·1
663–04	Do.	Do.	69·80	30·20	67·01	46·77	19·8
769–04	Do.	Karnool	69·62	30·38	68·96	48·00	31·6
816–04	Do.	Do.	66·65	33·34	67·95	45·29	20·4
817–04	Do.	Do.	69·43	30·57	70·69	49·08	22·9
1049–04	Chitamidalu	Bellary ...	68·01	31·99	69·19	47·05	17·7
1050–04	Peddamidalu	Do.	67·34	32·66	67·78	45·51	19·6
1054–04	Do.	Do.	67·19	32·81	67·59	45·41	18·9
1088–04	Castor seed, small	Do. ...	68·58	31·42	65·19	44·70	21·2
110–04	Castor seed	Anantpur ...	69·25	30·75	69·62	48·21	29·6
501–04	Do.	Do. ...	67·51	32·49	67·84	45·79	23·7
539–04	Do. big	Cuddappah	71·33	28·67	63·97	45·62	23·2
540–04	Do. small	Do. ...	61·66	38·34	57·46	35·42	9·0
449–04	Castor seed	Nellore	69·23	30·77	60·31	41·75	14·6
450–04	Do.	Do.	70·49	29·51	68·53	48·30	16·4
316–04	Do.	Salem	66·12	33·88	63·42	41·93	21·5
345–04	Do.	Do.	64·67	35·33	67·19	43·45	26·7
446–04	Do.	Do.	68·00	32·00	71·12	48·36	30·0
447–04	Do.	Do.	68·57	31·43	61·68	42·30	14·0
566–04	Do.	Do.	72·41	27·59	70·10	50·75	34·8
662–04	Do.	Do.	70·77	29·23	67·61	47·84	33·1
1035–04	Do.	Do.	68·81	31·19	69·67	47·93	31·1
1060–04	Do.	Do.	70·43	29·57	65·79	46·33	27·4
1061–04	Do.	Do.	69·92	30·08	67·43	47·14	33·2
1202–04	Do. large	Do.	70·68	29·32	64·62	45·67	30·7
1203–04	Do. small	Do.	66·39	33·61	67·20	44·61	18·1
1229–04	Do.	Do.	70·99	29·01	70·93	50·35	36·2
1417–04	Castor seed, big	Coimbatore ...	70·90	29·10	67·51	47·86	27·5
1418–04	Castor seed, small	Do.	65·75	34·25	63·16	41·52	14·6
1055–04	Sithamanakku ...	Madura	68·95	31·05	64·10	44·19	21·9
1056–04	Do. ...	Do.	67·77	32·23	62·51	42·36	18·0
1057–04	Periamanakku ...	Do.	62·34	37·66	56·22	35·04	39·3
1058–04	Do.	Do.	70·34	29·66	59·76	42·03	29·0
1059–04	Katamanakku ...	Do. ...	66·42	33·58	70·65	46·92	27·1

Sample No.	Vernacular Name.	District.	Kernel. Per cent.	Shells. Per cent.	Oil in Kernels. Per cent.	Oil in wholeseed. Per cent.	Weight of 100 seeds. Grms.
		Bombay Presidency.					
187–04	Castor seed ...	Ahmedabad	71·84	28·16	58·85	42·27	25·7
402–04	Do.	Kaira	72·30	27·70	64·50	46·63	37·2
459–04	Diveli	Surat	73·15	26·85	64·77	47·37	22·6
243–04	Castor seed	Nasik	73·24	26·76	55·24	40·45	40·8
249–04	Do	Poona	74·08	25·92	64·41	47·71	41·9
460–04	Diveli	Do.	75·98	24·02	63·75	48·43	45·8
256–04	Castor seed	Sholapur	68·17	31·83	63·22	43·09	19·8
268–04	Do.	Dharwar	65·10	34·90	65·69	42·76	16·0
326–04	Do.	Satara	73·05	26·95	61·30	44·77	37·3
475–04	Do.	Bijapur	72·43	27·57	65·43	47·39	37·0
1175–04	Do.	Belgaum	70·82	29·18	71·95	50·95	42·8
1179–04	Do.	Do.	74·36	25·64	63·87	47·49	31·2
1183–04	Do.	Do.	69·05	30·95	65·41	45·16	23·2
		United Provinces.					
676–04	Castor seed, large	Sultanpur	71·35	28·65	68·46	48·84	55·3
677–04	Castor seed, large	Do.	69·97	30·03	66·46	46·52	58·9
678–04	Castor seed, small	Do.	69·05	30·95	64·45	44·50	19·4
679–04	Castor seed, small	Do.	70·62	29·38	64·28	45·39	21·5
931–04	Randi, large	Cawnpore ...	70·33	29·67	65·66	46·17	36·4
932–04	Do. small	Do.	67·98	32·02	65·77	44·77	20·1
981–04	Do. large	Do.	73·01	26·99	61·89	45·18	31·4
988–04	Do. small ..	Do.	71·42	28·58	64·13	45·80	20·3
982–04	Do. large ..	Partabgarh	60·49	39·51	64·20	38·83	40·8
983–04	Do. ...	Do.	46·95	35·05	64·12	41·64	38·8
989–04	Do.	Do.	67·50	32·50	66·27	44·73	20·0
990–04	Do.	Do.	68·50	31·50	65·56	44·90	20·0
984–04	Do.	Aligarh	73·71	26·29	62·92	46·37	45·6
985–04	Do.	Do.	72·48	27·52	64·38	46·66	47·8
991–04	Do.	Do.	68·65	31·35	62·71	43·05	20·1
992–04	Do.	Do.	67·96	32·04	63·33	43·03	20·6
986–04	Do.	Unao ...	71·71	28·29	66·43	47·63	46·6
987–04	Do. large	Do. ..	72·09	27·91	67·60	48·73	50·6
993–04	Do.	Do. ..	67·06	32·94	65·62	44·00	16·7
994–04	Do. ...	Do.	68·02	31·98	65·97	44·87	17·2
		Central Provinces.					
107–04	Undi	Jabalpur ...	73·60	26·40	60·69	44·66	59·7
117–04	Do.	Hoshangabad	70·60	29·40	60·72	42·85	43·5
541–04	Badi Andi ...	Do.	72·33	27·67	63·46	45·90	55·3
119–04	Castor ...	Nimar	70·14	29·86	61·42	43·07	69·0
134–04	Do., large	Damoh	72·72	27·28	62·93	45·76	46·7
135–04	Do., small	Do.	69·56	30·44	60·70	42·22	14·2
161–04	Andi	Raipur	59·14	40·86	62·03	36·68	12·9
169–04	Jada	Sambalpur	70·02	29·98	65·09	45·57	19·5
177–04	Castor	Do.	68·50	31·50	65·58	44.93	18·0
195–04	Kachhari	Balaghat	69·72	30·28	64·95	45·28	32·0
196–04	Wevri	Do.	73·11	26·89	67·98	49·70	12·6
298–04	Castor	Narsingpur	71·20	28·80	61·16	43·54	25·3
226–04	Do.	Chanda	69·00	31·00	62·00	42·78	27·5
227–04	Do.	Do.	68·44	31·56	64·49	44.13	23·1
228–04	Do.	Do.	63·38	36·62	64·09	40·62	23·9
229–04	Do.	Do.	69·03	30·97	61·35	42·34	26·0
545–04	Yerandi	Wardha	66·14	33·86	58·39	38·61	12·8
550–04	Do.	Do. ...	74·93	25·07	63·80	47·80	50·3
576–04	Andi Badi	Chhindwara ..	67·30	32·70	69·46	46·74	41·6
577–04	Do. Chhoti	Do.	71·23	28·77	64·21	45·73	23·8
706–04	Yendi ...	Betul ...	70·92	29·08	64·36	45·64	24·3
915–04	Castor, large .	Bilaspur ...	73·61	26·39	64·82	47·71	53·5
918–04	Do., small...	Do. ...	64·03	35·97	64·63	41·38	15·8
1223–04	Andi Badi	Nagpur ...	72·91	27·09	63·07	45·98	49·0
1224–04	Do. Chhoti	Do. ...	71·21	28·79	65·83	46·87	27·1

AVERAGE COMPOSITION.

	Madras.	Bombay.	Central Provinces.	United Provinces.
Moisture ...	4·85	4·11	3·98	4·17
Oil	63·62	56·71	63·72	63·22
Albuminoids	18·15	20·75	20·88	19·36
Soluble Carbohydrates	8·88	14·46	7·52	8·98
Woody fibre	1·53	·95	1·03	1·02
Soluble mineral matter	2·92	2·87	2·72	3·01
Sand	·05	·15	·15	·15
	100·00	100·00	100·00	100·00
Total Nitrogen	3·06	3·41	3·56	3·22
Albuminoid Nitrogen	2·90	3·32	3·34	3·10

Average proportion of shells and kernels :

	Madras.	Bombay.	Central Provinces.	United Provinces.
Kernels, per cent.	68·79	71·81	69·88	69·34
Shells, per cent.	31·21	28·19	30·12	30·66

Composition of whole seed, calculated on the assumption that the shells are entirely indigestible "woody fibre" :

	Madras.	Bombay.	Central Provinces.	United Provinces.
Moisture	3·34	2·95	2·78	2·89
Oil	43·75	40·70	44·51	43·93
Albuminoids	12·50	14·96	14·60	13·40
Soluble Carbohydrates	6·10	10·35	5·26	6·23
Woody fibre	32·26	28·87	30·84	31·37
Soluble mineral matter	2·01	2·06	1·90	2·08
Sand	·04	·11	·11	·10
	100·00	100·00	100·00	100·00
Total Nitrogen	2·10	2·44	2·48	2·23
Albuminoid Nitrogen	1·99	2·38	2·33	2·15

SESAMUM INDICUM—(*Vern. Til, Jingelly.*)

	Area in British India. Acres.	Yield. Tons.
Grown as single crop	4,000,000	} 300,000[1]
Grown in mixed crop	500,000	

The specimens of this oil seed varied considerably in size and in colour, as well as in the amount of oil. The shape of the different seeds remains constant, but some are nearly twice as heavy as others ; the weight of 100 seeds varied from about ·18 to ·35 grammes in extreme cases and, excluding such exceptions, the

[1] This yield suffers great fluctuations from year to year.

variation may be said to be from ·22 to ·33 grammes. The *colour* is commonly either white, black, or brown, though some of the Central Provinces seed is more of a brick-red. Different specimens, however, vary much in colour between the limits named.

Most of the specimens were fairly free from admixture of earth, and they were quite free from seeds of other plants. On the other hand, no sample could be called pure, for there was invariably a greater or less quantity of varieties other than the predominating one ; in some cases the mixtures could not be designated by any colour in particular.

Regarding the percentage of oil, the variation is from about 48 to 52, though some specimens contained as much as 58 per cent., and some as little as 45 per cent. These variations appear to be independent of variety, Province or climate.

The specimens are arranged in the accompanying statement according to the colour of the seed as far as possible :—

Sample No.	District.	Province.	Oil. Per cent.	Weight of 100 seeds. Grms.
		White.		
13—04	Gurgaon	Punjab	46·49	·323
82—04	Kangra	Do.	53·06	·286
93—04	Umballa	Do.	51·12	·335
151—04	Rawalpindi	Do.	51·98	·280
75—04	Seoni	Central Provinces ...	49·38	·189
100—04	Jabalpur	Do. ...	47·31	·197
114—04	Hoshangabad	Do. ...	47·22	·250
121—04	Nimar	Do. ...	51·82	·282
129—04	Damoh	Do. ...	45·15	·224
173—04	Sambalpur	Do. ...	51·17	·233
198—04	Balaghat	Do. ...	52·43	·235
204—04	Narsingpur	Do. ...	48·64	·251
211—04	Chanda	Do. ...	52·45	·228
213—04	Do.	Do. ...	50·73	·231
290—04	Mandla	Do ...	50·89	·215
186—04	Ahmedabad	Bombay Presidency ...	51·14	·319
247—04	Poona	Do. ...	51·22	·297
257—04	Sholapur	Do. ...	57·79	·286
253—04	Ahmednagar	Do. ...	55·27	·304
265—04	Kanara	Do. ...	55·57	·256
266—04	Dharwar	Do. ...	56·07	·339
		Black.		
18—04	Chenab Canal	Punjab	48·27	·357
87—04	Muzaffergarh	Do.	48·51	·378
67—04	Montgomery	Do.	46·41	·291
136—04	Sialkot	Do.	47·15	·313
101—04	Jabalpur	Central Provinces ...	47·37	·228
102—04	Do.	Do. ...	45·45	·232
199—04	Balaghat	Do. ...	50·44	·242
112—04	Hoshangabad	Do. ...	49·90	·274
205—04	Narsingpur	Do. ...	47·47	·263

Sample No.	District.	Province.	Oil. Per cent.	Weight of 100 seeds. Grms.
		Black (concld.)		
130-04	Damoh	Central Provinces ...	45·45	·257
291-04	Mandla	Do.	47·56	·210
157-04	Raipur	Do. ...	49·07	·219
168-04	Sambalpur ...	Do.	50·77	·264
242-04	Nasik	Bombay Presidency	51·19	·337
264-04	Kanara	Do.	55·94	·318
259-04	Dharwar	Do.	51·50	·356
		Brown.		
8-04	Hissar	Punjab	48·71	·335
93-04	Umballa ...	Do.	47·92	·371
142-04	Gujrat ...	Do.	48·27	·350
289-04	Mandla ...	Central Provinces	47·61	·220
		Red.		
113-04	Hoshangabad	Central Provinces	53·01	·319
175-04	Sambalpur	Do.	55·97	·317
214-04	Chanda	Do.	52·70	·315
215-04	Do. ...	Do.	51·86	·296
216-04	Do. ...	Do.	51·51	·326
218-04	Do.	Do.	50·34	·305
185-04	Ahmedabad	Bombay Presidency	52·79	·318
		White, Brown and Black mixed.		
120-04	Nimar	Central Provinces ...	55·52	·335
171-04	Sambalpur ...	Do. ...	51·54	·253
212-04	Chanda	Do.	49·98	·201
217-04	Do. ...	Do.	53·25	·212

The following illustrates the average composition of the seed :—

	White.	Black.	Brown.	Red.
Moisture	5·11	4·78	4·61	4·76
Oil ...	49·90	48·57	47·60	50·16
Albuminoids	16·25	18·93	18·73	18·50
Soluble Carbohydrates	17·79	15·88	16·41	15·69
Woody fibre	4·26	4·03	4·05	4·17
Soluble mineral matter	6·00	6·75	6·87	5·76
Sand ...	·69	1·06	1·73	·96
	100·00	100·00	100·00	100·00
Total Nitrogen ...	3·06	3·13	3·09	3·06
Albuminoid Nitrogen ...	2·53	3·03	3·01	2·96

THE EFFECT OF TRANSFERRING OILSEEDS TO ANOTHER PROVINCE.

It is known that the quality of a plant may be changed in one or another respect by transference to a different soil or climate. Thus it has been found that sugarcane may produce a poorer juice after such a change, though this is not universally the case.

After the oil-seeds had been tested, and it was known that some samples contained appreciably more oil than others of the same botanical order, specimens of the richer were in several cases grown at farms where seed of poorer quality was generally produced. Excepting in one case, the imported seed was not examined and only the newly-grown seed submitted to analysis. Although, in some cases, the latter was not so rich in oil as was the sample that had been originally tested in this laboratory, there was, strictly speaking, nothing to compare the newly-grown crop with. This precaution was, however, taken in the case of some linseed which was brought from different places to Lyallpur in the Punjab, and in the subjoined statement the percentage of oil in the original seed and in the crop is set out :—

	Original seed.	Produce of 1905.	Produce of 1906.
Linseed White from Cawnpore ...	44·62	41·28	39·90
Do. do. do. Khandwa ...	44·96	44·18	42·93
Do. do. do. Damoh ...	45·34	43·07	43·57
Do. Brown do. Partabgarh ...	43·17	40·98	38·31
Do. do. do. Cawnpore ...	42·05	40·97	39·43
Do. do. do. Sholapur ...	41·13	40·42	38·82

There has thus been a decline throughout. It remains to be seen whether this decline ceases, and whether after acclimatization the seed will regain its former richness or not.

THE POT-CULTURE HOUSE AT THE AGRICULTURAL RESEARCH INSTITUTE, PUSA.

By

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A Pot-culture House has been erected at the Agricultural Research Institute, Pusa, in Behar, and it is probable that a description of it, the apparatus employed, and the methods in use, may be of interest to others who utilize this means of investigation.

The Structure.—This includes two parts: the one being a masonry building in which operations may be conducted and plants grown at times when protection from sun and rain is desired, the other an enclosure protected from birds and large insects by wire-netting. The former has an area of 42 × 37 feet, the latter 42 × 47 feet.

The cultivation jars are placed on small trollies in the manner so common to these installations, and these trollies run on rails which extend through both enclosures. By means of a cross-rail, these trollies may be readily conveyed to any part of the building. The nature of the structure is shown in illustration No. 1. No. 2 shows the interior of the wire enclosure. Illustration No. 3 shows that portion of the house which is employed for mixing soils, introducing fertilizers, filling cultivation jars, or the execution of laboratory operations on a table. The floor is masonry. The table is fixed against the wall.

The Cross-rail Trolly.—Two patterns of cross-rail trolly are employed in different Institutes. The one (which is also common to the French railway system) runs on a rail on the same level as the general system, and the trolly is itself above the general level. This pattern is used in the Pot-Culture House at the Woburn Agricultural Station in England. The other pattern runs on rails *below* the general level, and the top of the trolly coincides with this. This pattern is used at Pusa. In the first instance the cross-rail was 13 inches below the ground-level, but as this proved an inconvenience when stepping across it, the axles were recently altered and the cross-rail raised to 6 inches from the ground-level as seen in Plate No. 4. It is indeed simple to construct a trolly which does not require the cross-rail to be more than about 4 inches below the ground-level, and the less this depression, the more convenient for the pedestrian.

No. 5, CULTIVATION JAR.

Cultivation Jars. Both glass and stoneware cultivation jars from Europe have been used, but it was found that quite suitable ones could be obtained in India, and at a less cost. The illustration No 5 shows the pattern which has been adopted. It has no projecting tubulure at the base, but merely a hole. Projecting tubulures are somewhat readily broken, and a simple hole in the jar is sufficient. Very generally, indeed, this is closed by a cork, as in most experiments no drainage occurs. The sizes employed are :—

	Inside depth.	Diameter.	Soil required to fill one jar.
	Inches.	Inches.	Kilos.
A	12	9	15
B ...	16	9	22
C	22	9	29
D ...	16	12	31
E	22	12	54

The smallest of these appears to be quite large enough for the perfect development of specimens of most of our field crops.

The Large Beam Scale. Principally in order to maintain the proportion of moisture in soils as constant as possible, but also for other reasons, the jars of any experiment are weighed every day. For this purpose it is necessary to determine the weight with considerable precision. A differential scale is not sufficiently delicate for this purpose, and a plain beam scale which turns to five grammes with a maximum load of 100 kilos has been adopted. It is seen in illustrations Nos. 6 to 9. Its only peculiar feature is the pair of stirrups, or hooks, in which the jar rests when being weighed. A fruitful source of damage to large plants is the necessity for lifting jars by hand. Even the small ones are so heavy that the operator has to bend over the jar when lifting it, resulting not infrequently in broken plants, and the stirrups were designed in order to obviate this. When used, the trolly is brought to the scale, and the stirrups or hooks are placed on either side of the jar as in the illustrations Nos. 6 or 8; the beam is then depressed by hand until the stirrups will pass under either edge of the jar as in illustration No. 7, or the hooks under the handles (No. 9). The correct weights may then be placed on the pan. Weighing necessarily occupies some time, but as the jars can be dealt with at the rate of 30 per hour, this is not inordinately long, and admits of valuable information regarding loss of water, as well as the regulation of the moisture in the soil. In some cases it would be well to suspend the beam scale from a pulley on an overhead rail. For example, if two rows of jars are on a trolly, the weighing cannot be conveniently executed with a scale hung from a fixed point, but naturally the above arrangement would entail a slight extra expense.

Filling Jars. The usual practice of experimenters in Europe is to fill the *dry* soil into the cultivation jars, and to add water afterwards at the surface. For many soils this procedure is doubtless sufficient, but for some, such as the fine alluvium of the Indo-Gangetic plain, I have found it inapplicable. When such soils are air-dry, they occupy a larger volume than when

damp, and the consequence is that, if water is added at the surface of a jar of such soil, cracks form which never fill up again, and subsequently added quantities of water are apt to pass straightway to the bottom. In order to obviate this, and indeed as a more perfect method of introducing water uniformly into soils, the filling is effected in the following manner. The weighed quantity of air-dry soil (after adding fertilisers where this is desired) is spread upon the floor. A measured quantity of water is then added from the mouthpiece of a wash bottle, or preferably from a funnel with "rose" attached, in such a way that the water falls on the soil in drops. After adding some of the water, the soil is turned over and any damp lumps broken down by hand. Further portions of the water are then added with alternate working by hand until the whole quantity is uniformly mixed with the soil. The following figures will illustrate the process. 15 kilos of air-dry Pusa soil, spread on the floor, received 1·46 kilos of water about one-fourth at a time. For this soil the quantity of water so introduced is about 10 % of the soil. For other soils less or greater amounts of water are introduced, according to their nature. The aim is to introduce a quantity of water which will damp the earth, without, however, making it so damp that the clay could be "puddled" when the jar is filled.

The damped earth is now filled into the jar, and as each handful is introduced, it is levelled and pressed in quite firmly. It is difficult to explain in writing exactly how firmly, but the "doubled" or "clenched" hand is pressed down on it nearly as hard as the operator can do this, without in any way beating the soil. The method results in very uniform packing indeed, the variation being certainly less than 5 % by volume between extreme cases, even when more than one operator fills a set of jars. By this method the earth becomes nearly as compact as in the field. In a set of jars recently filled, one cubic foot contained 76 lbs., whilst the subsoil of the locality contained 75 to 87 lbs. per cubic foot.

Addition of fertilisers.—Most substances, which it is desired to add, are introduced while the soil is in the air-dry state. The weighed substance is first mixed intimately with a small handful

of the soil on a board, and a further handful of soil is then mixed in also. This dry powdery material is then scattered uniformly over the main portion of dry soil lying on the floor and the mixture of the whole completed.

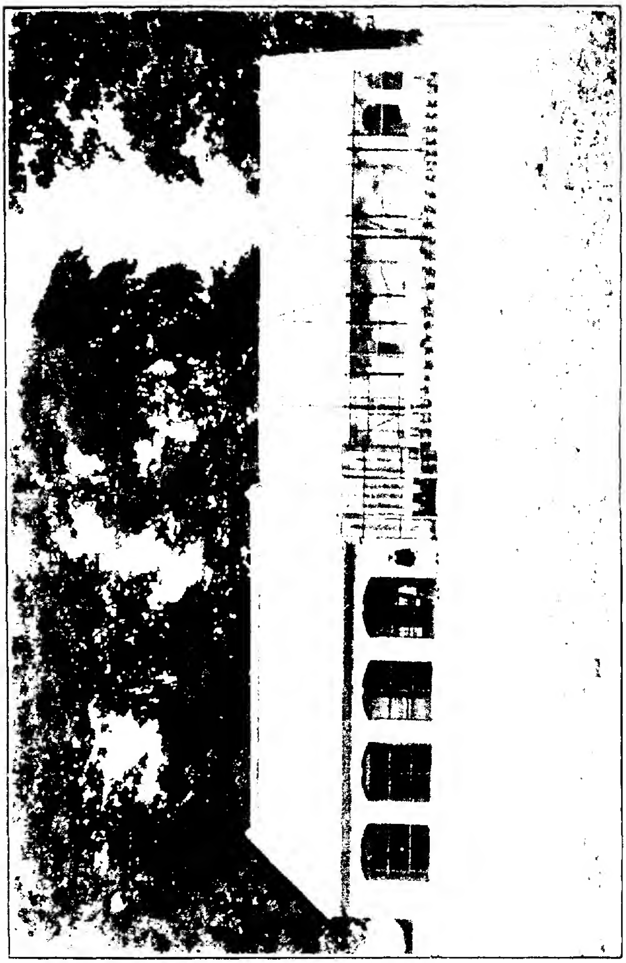
Nitrates are sometimes added to the growing plant in irrigation water, but in other cases such substances are added to the soil as described.

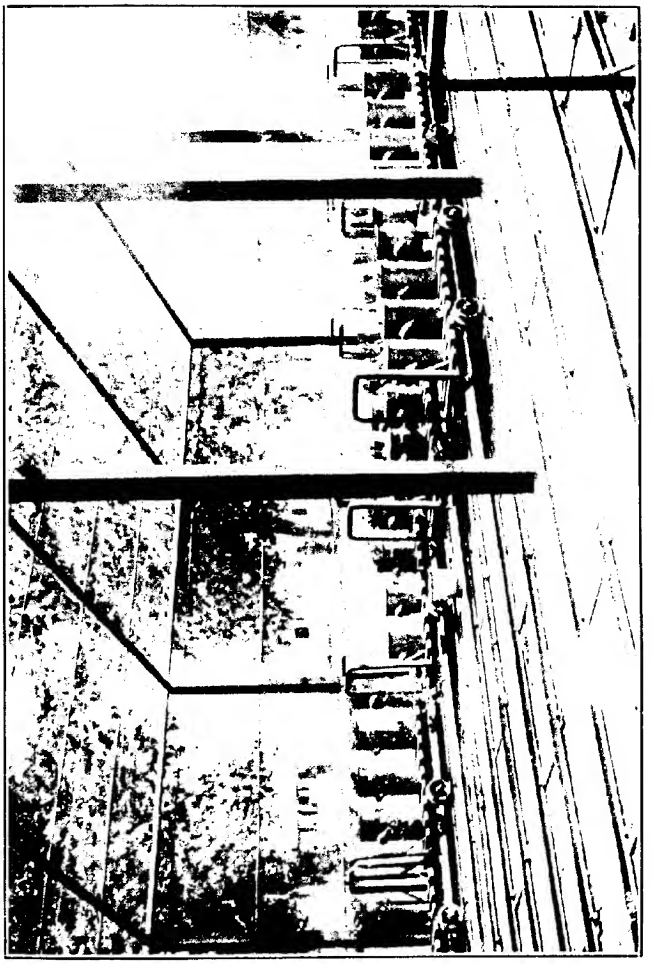
Addition of water. Experimenters have employed various methods of adding water. By some it is simply poured on to the surface; by others it is introduced to the bottom of the jar by means of a tube, or more rarely through a porous cylinder placed vertically in the upper part of the soil. So far as I am aware, the latter has generally proved a failure. The addition of water at the surface of some Indian soils had, however, been so productive of cracking and caking, that experiments were made during the cold weather of 1905-6 to determine whether the water could not be introduced below the surface, so as to preserve this in an "open" condition. Both deep and shallow jars were employed, and three formed a unit. To one the water was added at the surface, to the second it was introduced by a tube to the bottom of the jar and into the third it was introduced by means of a porous cylinder. This latter method is very commonly employed to irrigate trees in India, in which case a porous spherical vessel is sunk in the ground near the base of the tree and kept full of water. The same weight of water was always added to the three jars of any one set. No manure was employed. The plants (oats) were reduced to 10 in each jar after germination, and afterwards to five, and from the weight of the thinnings an estimate was made of the rate of growth; finally, the weight of the harvested plants was obtained. The result is shown diagrammatically (chart No. 10), and it is clear that, at least for this soil, there can be no doubt about the great advantage of introducing water below the surface. The jars to which water was added at the base produced the most, those to which it was introduced through the porous cylinders came next, and, thirdly, those irrigated at the surface. A difficulty was indeed experienced in adding

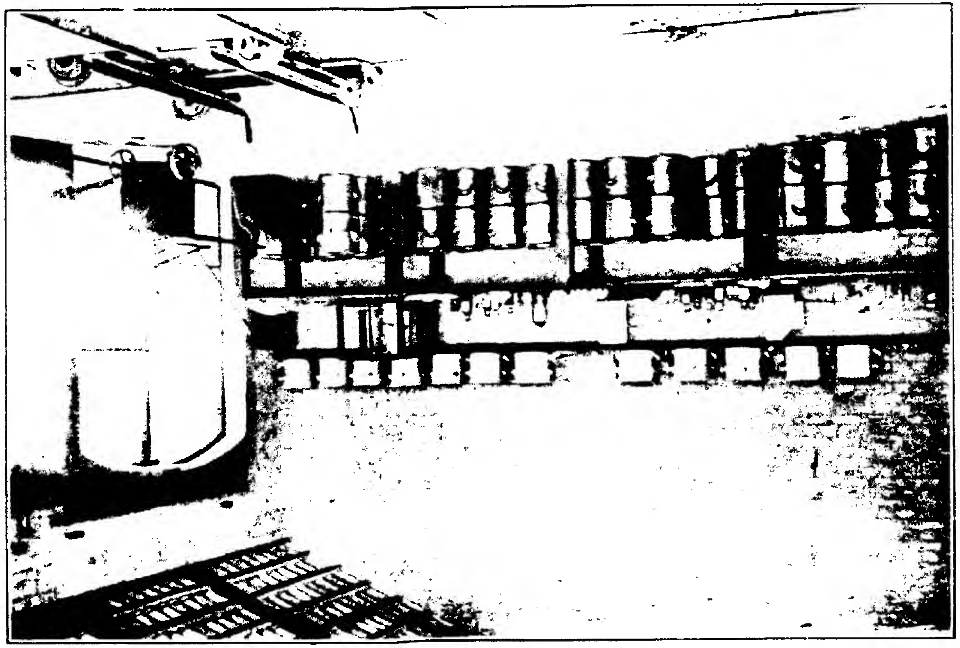
water quickly by either of the former methods, because it percolated very slowly not only through the porous cylinders but also into the soil at the base of the jars. Moreover, the latter method necessitated the use of a funnel and tube which were inconvenient.

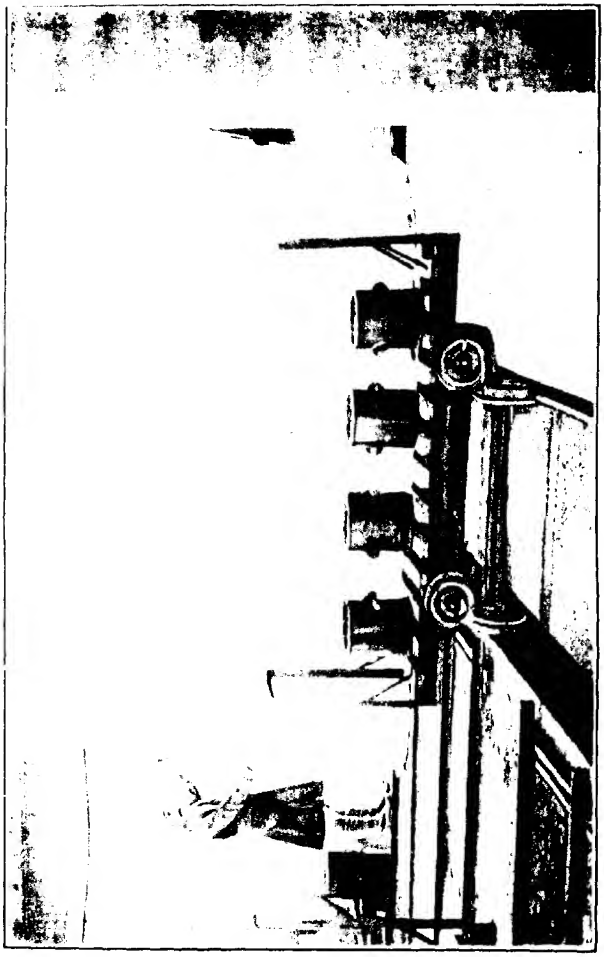
For the present, porous cylinders are employed, and in order to admit of the more expeditious percolation of the water, they are pierced with small holes in the side, and are also made as large as is compatible with the size of the jars. The quantity of water transpired by plants when growing vigorously is considerable—a dozen young wheat plants may transpire upwards of one kilogramme per day, and usually the whole of this cannot be re-introduced into the soil in less than a couple of hours. The result is, however, entirely satisfactory so far as the surface soil is concerned, since it retains its loose pulverulent character and cracks and caking are avoided even when the proportion of water is maintained at 20 %.

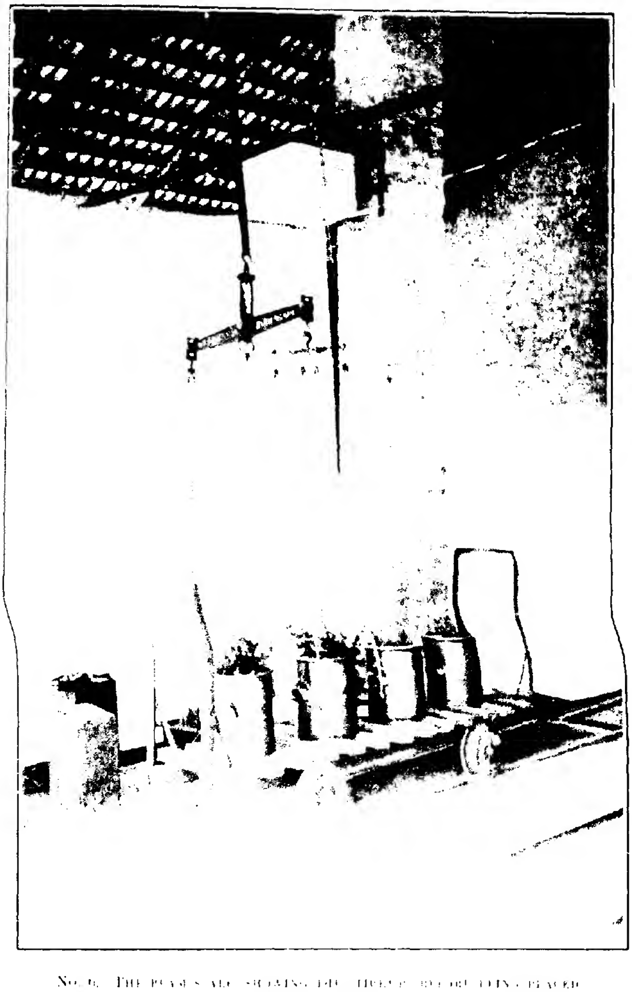
Thinning.—More seeds are usually sown in the first instance than the number of mature plants ultimately required. This is in part necessary since faulty germination is so frequent. But in addition to this, surplus plants provide a means of forming an estimate of the weight of the plants during the initial period of an experiment. After the young plants have fairly established themselves, the number may be reduced, and those which are cut out, weighed: from which the above data are calculated. Discretion is naturally used as to which plants are cut out, and these may be smaller than those remaining, so that the estimate involves some inaccuracy, but with good seeds, producing uniform germination, this source of inaccuracy is very small. Thinning is more particularly useful, for annuals, during the earlier stages of growth, before the plants have tillered much; if done later, the remaining plants will not develop more than if the number had not been reduced.



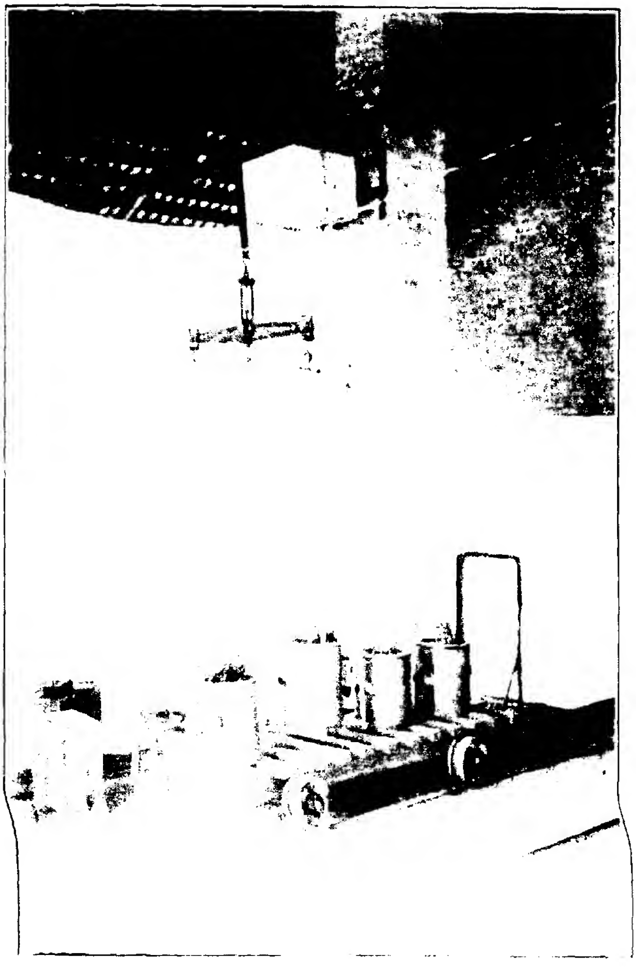




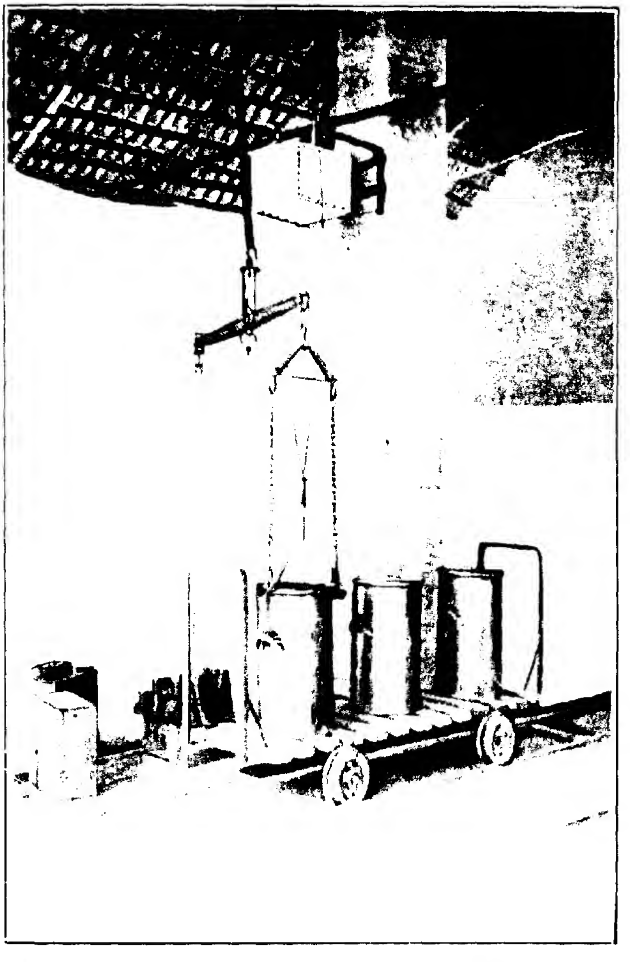




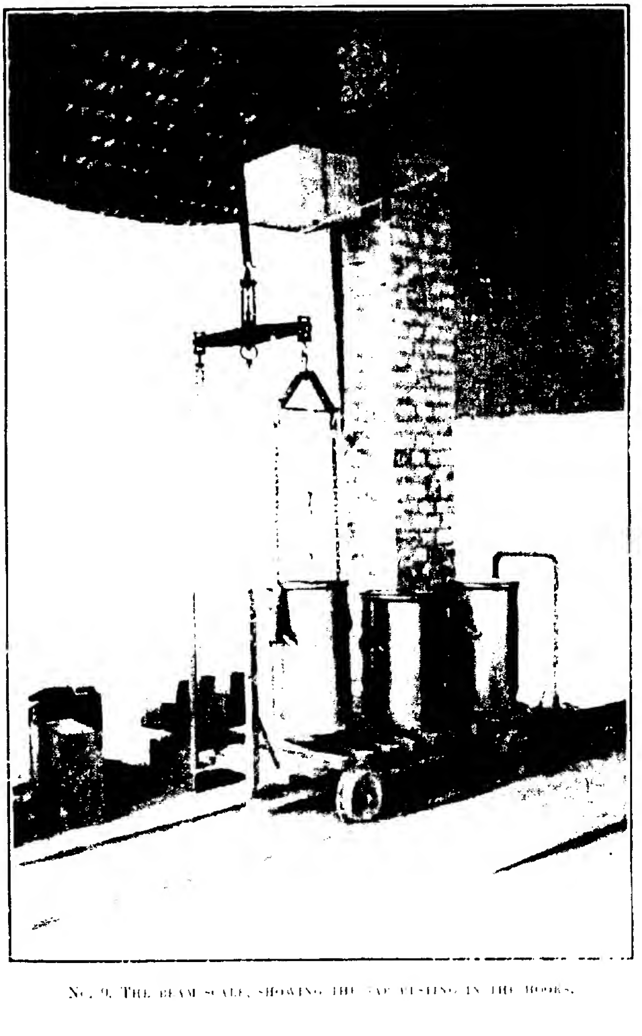
No. 6. THE [illegible] PLACED UNDER THE JAR.



No. 7. The beam scale showing the car resting in the stirrups.



No. 8. The beam scale, showing the hooks before attachment to the jar.



No. 9. The Beam Scale, Showing the Vat Resting in the Hooks.

EXPERIMENTS ON THE AVAILABILITY OF PHOSPHATES AND POTASH IN SOILS.

BY

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During the years 1904 to 1906 plants have been cultivated by pot-culture methods, with and without the aid of fertilizers, in a number of soils which have been brought from different parts of India.

The principal object in view has been to test how far the chemical method, which was advanced by Dyer in 1894 for the estimation of a sufficiency or deficiency of phosphate or potash in soils (*vide* Trans. Chem. Soc., **65**., 115-167, and Philos. Trans. Royal Soc., Series B., Vol. 194, pp. 235-290) is reliable generally. This method consists in the digestion of the soil at room temperature in a 1 per cent. solution of citric acid for seven days, on six of which the mixture is agitated frequently The solution is then separated by filtration and the phosphoric acid and potash present in it determined. Although such a method is obviously empirical, Dyer standardized the value of its indications by means of a considerable number of soils of the Rothamsted Experiment Station, the agricultural value of which for certain crops is well known. The outcome of his work may be suitably quoted from the second of the papers named. "The probable limit denoting phosphatic deficiency for cereals seems to be, as deduced from this investigation, between ·01 and ·03 per cent. of citric-acid-soluble phosphoric acid in the surface soil. That is to say, a percentage as low as ·01 seems to denote an imperative demand for phosphatic manure, while as much as ·03 would seem to

indicate that there is no such immediate necessity. For root crops, especially turnips, the limit would probably be higher." (Page 269.) "In the paper on the Hoos Field barley soils a tentative conclusion was drawn that the percentage of citric-acid-soluble potash in surface soil, indicative of potash hunger for cereals, would probably be below ·005. On considering the results of the wheat soil analyses and other results obtained in the interim by other workers who have applied the method to other soils known from other experience to be responsive to the influence of potassium salts, the author would now be inclined to modify this conclusion by suggesting that when a soil shows as much as ·01 per cent. of citric-acid-soluble potash, by this process, it may be regarded as not demanding any special application of potassium salts." (Page 275.)

There is one point which must be referred to here. One of the first questions raised, after the publication of Dyer's first paper, was in relation to calcareous soils. Obviously the calcium carbonate present in soils will forthwith react with the citric acid resulting in the formation of calcium citrate and carbonic acid, and the soil is then in contact with a solution of these substances together with any excess of citric acid.

In order to illustrate the bearing of this point, the following figures show the quantities of calcium carbonate in a soil which neutralize each tenth part of the citric acid employed; or since 10 grms. of the acid are employed per 100 grms. of soil, the figures show the percentage of calcium carbonate neutralized by each 1 grm. of the acid.

Citric acid. Grms.	Calcium Carbonate. Grms.
1	1·43
2	2·86
3	4·29
4	5·72
5	7·15
6	8·58
7	10·01
8	11·44
9	12·87
10	14·30

Thus even if the soil contains so high a proportion of calcium carbonate as 7·15 per cent., one half the citric acid remains, and the majority of soils contain considerably less than this. The Rothamsted soil, on which Dr. Dyer worked, contains only about 3 per cent. of calcium carbonate, which would alter the composition of the acid solution in only a minor degree.

Two of the soils which have been included in my experiments contained, however, upwards of 40 per cent. of calcium carbonate, and the citric acid becomes in such a case entirely neutralized.

Dr. Dyer in a postscript to his first paper recommends that in such cases an additional quantity of citric acid corresponding to the quantity of calcium carbonate "might reasonably be added to the solution." If, however, this is done with these highly calcareous soils, the soil constituents are not merely exposed to a solution of citric acid, but citric acid plus a large amount of calcium citrate, and carbonic acid. And indeed an even more important circumstance is the fact that the particles of calcium carbonate are entirely dissolved. Phosphate, which in such a soil may be present in the interior of these particles, is thus brought into actual contact with the solvent, whereas the idea underlying the use of the solvent is, that it will only be in contact with phosphates which are exposed to plant roots or soil-aqueous solutions, *i.e.*, to phosphates which are on the *exterior* of soil particles. It is hardly, therefore, to be expected that the same result will be obtained as if the soil particles remain as far as possible intact. The circumstance emphasizes a weak point in the method. The following figures show the difference in result obtained (*a*) by the use of the usual 1 per cent. solution, and (*b*) this solution plus the extra citric acid, respectively :—

	By 1 per cent. citric acid.		By sufficient citric acid to neutralize the calcium carbonate plus the usual 1 per cent.	
	P_2O_5.	K_2O.	P_2O_5.	K_2O.
Seeraha soil containing 41·6 per cent. $CaCO_3$	·001	·008	·019	·043
Pusa soil " 38·63 "	·0003	·0062	·0015	·0085

It will be seen presently that the Seeraha soil is certainly much in need of phosphatic manure, and that potassium sulphate produced positive effects in some cases. The Pusa soil has proved to be much in need of phosphates. If then the extraction had been made with the extra citric acid, the analysis would have indicated a very doubtful requirement of phosphates in the Seeraha soil, and certainly no requirement of potash. The pot-cultures on the other hand leave no doubt that these soils respond to phosphatic manures, and the Seeraha soil probably to potash.

The literature on the subject includes two papers. One by T. B. Wood (Trans. Chem. Soc., 1896, **69,** p. 290), where evidence is produced, showing that the use of the extra quantity of citric acid would have given a result indicative of a sufficiency of readily available phosphates, when in fact the soil responded to phosphatic manures; the other by Cousins and Hammond (Analyst, 1903, **28,** 238), where the evidence indicates the desirability of using the extra citric acid. This latter evidence relates, however, to land bearing bananas, a crop so entirely different from cereals that a quite different "limiting figure" may be applicable.

It is unfortunate that the conclusions on the subject are so contradictory. It seems to me preferable to adhere to the use of the simple 1 per cent. solution, and if, when it is applied to any particular class of soils, the limiting figure for phosphate or potash, as proved by actual trials with plants, is shown to be different from that which Dyer deduced with the Rothamsted soils, to then adopt this particular limiting figure. It is to be recollected that the method is not merely empirical, but that a limiting figure which is applicable to one description of plant, will not necessarily apply to another plant of widely different botanical character, period of growth, root range, etc. Dyer himself emphasized that the limiting figure he found would not necessarily apply to other crops than cereals, and "that for root crops, especially turnips, the limit would probably be higher" (*vide* ante).

It must be held to be a matter for regret that nearly all who have proposed methods for the estimation of available plant

food, have employed an acid as the solvent. Such solvents necessarily attack the surface of the particles in a manner wholly different from the neutral solutions present in the soil, and as has been pointed out, dissolve up particles of calcium carbonate entirely, thus exposing plant food to the solvent, which in the soil is present in the *interior* of particles. No doubt the quantity of material, which a neutral solvent will dissolve, is much less than would be brought into solution by an acid solvent, and difficulties arise in the determination of such minute quantities, but the fundamental defect attaching to acid solvents nevertheless remains.

The soils which have been subject to experiment at Dehra Dun and (later) at Pusa, comprise the following :—

Soil.	Containing :—		
	Organic Nitrogen. %	Available. P_2O_5 %	Available. K_2O %
Dehra Dun ...	·181	·146	·022
Seeraha Behar ...	·046	·001	·008
Pusa-Behar ...	·060	·0003	·006
Shillong G ...	·228	·011	·010
" B ...	·193	·005	·012
Bangalore ...	·059	·0047	·0023
Godavari V ...	·071	·042	·010
" R ...	·084	·011	·005

For cereals, which have so far been principally included, the Dehra Dun soil would be considered sufficiently well supplied with phosphates and potash, and the Godavari V soil probably so ; the other six soils would be expected to respond to phosphates, and four, namely, Seeraha, Pusa, Bangalore and Godavari R to potash.

The first two years' experiments were made while the chemical laboratory was at Dehra Dun, where the conditions for this class of work were in many respects opposed to accuracy. Only a thatched hut was available, and the cultivation jars had to be moved by hand ; nor was any means available for maintaining the moisture very constant, such we now have. But the chief obstacle

proved to be rats and squirrels, which could not be kept away at night and damaged in great measure many of the mature plants.

In some of these cases an estimate of the weight of the entire plants was obtained when their number was reduced in each jar, and these figures aid in drawing conclusions.

The experiments of 1906 made at Pusa were free from such untoward incidents and are in consequence more reliable.

The details are set out in the following pages, but a graphic summary may be here inserted. If the sign + is employed to denote a positive result, whilst the sign – a negative one, ± where the outturn of grain is negative, but that of total dry matter positive, and ? where the indication is doubtful, the nett results will be seen at a glance.

	Phosphate:		Potash:	
	Expected.	Realized.	Expected.	Realized.
Dehra-Dun	–	–	–	......
Seeraha Behar	+	+ + ± +	?	+ + ±
Pusa-Behar	+	+	+	....
Shillong G	+	- + +	–	+ + +
" B	+	- - +	–	- - -
Bangalore	+	+ + +	?	- + -
Godavari V		± +	·	- - +
" R	+	+ ± +	+	- ± ±

This representation shows that great dependence may be placed on Dyer's method, as also his limiting figure for phosphates even in soils of a widely different nature. In the whole list, the cultivations have yielded a contradictory result in two cases. The Shillong B soil should have been benefited by phosphates, and if dependence were placed on the experiments at Pusa (carried out with the more perfect appliances), this exception would disappear. The Godavari V soil should hardly have responded to phosphatic manures, whilst it has done so to a greater or less extent.

The effect of potash is similarly characterized by contradictory results in two cases. The Shillong G soil has shown a

positive result where it was hardly to be expected. Dyer's test yielded ·01 % K_2O which is his limiting figure. The Bangalore soil should have given a positive result with potash manure, but has done so with only one crop out of three. It is always to be recollected that neither Dr. Dyer nor other experimenters have advanced this method as an absolute one for determining whether it will pay to apply specific fertilizers. On the contrary, it has been regarded as one which must necessarily be employed with some caution. Our knowledge of the nature of the phosphates and the potash compounds which actually exist in the soil is most imperfect, and, as Hall and Amos (Trans. Chem. Soc., 1906, **89**, p. 205), have pointed out, the amount of a soil constituent which passes into solution in a given time depends not only on its nature but also on its mass. Soils in different parts of India differ very widely in composition, and whilst we may apply the 1% solution to them without exception, it does not follow that the same limiting figure will apply equally to all. Finally, the nature of the plant which is grown must always play an important rôle in relation to this limiting figure.

Nevertheless, and although I make these several reservations, there cannot be any doubt that the method is proving generally useful for ordinary agricultural land, enjoying a rotation of crops, one of which is usually a cereal, and that the limiting figure proposed by Dyer is much more generally applicable than might have been expected.

The details of the experiments are set out in the following paragraphs.

Dehra Dun Soil.

This soil is derived from shale and limestone of the Himalayas and is a rich soil with excellent physical characteristics.

The chief analytical data are as follows :—

	Per cent.
$CaCO_3$	·41
Total P_2O_5	·366
Available P_2O_5	·146
Available K_2O	·022
Organic Nitrogen	·181

It was only employed in one season's experiments when wheat and gram were grown. The outturns were as follows :—

Manure.	Weight of whole crops (grms.).	
	1903-4 Wheat.	1903-4 Gram.
Nil	37·6	45·5
Nitrate ..	62·0	45·0
Nitrate and phosphate .	64·3	43·0

The same is set out graphically on the chart No. 1.

The Seeraha Soil.

This soil is representative of a large area in Behar and possesses two chief characteristics ; firstly, it consists entirely of very fine material, and like the whole Indo-Gangetic alluvium contains no stones ; secondly, about one-third of it is chalk.

The following are the chief analytical data :—

$CaCO_3$	41·6
Total P_2O_5	·097
Available P_2O_5	**·001**
Available K_2O	**008**
Organic Nitrogen	·046

It was employed during four seasons, the crops being cereals in each case. The results are set out in the following statement and on chart No. 2, from which it is evident that both phosphate and potash had a definitely positive effect.

Manure.	Weight of whole crop (grms.).				Weight of grain (grms.).			
	1903-4 Wheat.	1904 Murwa.	1904-5 Wheat.	1906 Kodo.	1903-4 Wheat.	1904 Murwa.	1904-5 Wheat.	1906 Kodo.
Nil	2·4	13·3	4·6	24·7	·7	5·4	1·6	12·3
Nitrate ..	2·1	63·9	11·5	43·9	·6	20·4	6·4	22·7
Nitrate and phosphate .	8·3	63·8	20·0	62·4	2·5	26·9	5·9	30·0
Nitrate, phosphate and potash	...	80·3	26·5	...	...	29·1	7·9	

The Pusa Soil.

This is similar in all respects to the Seeraha soil, but was irst included in the experiments in the rainy season of 1906.

The chief analytical data are as follows :

$CaCO_3$	38·63
Total P_2O_5	·10
Available P_2O_5	**·0003**
Available K_2O	**·0062**
Organic Nitrogen	·060

The crop grown was Kodo (Paspalum scrobiculatum), and the yields were as follows :

Manure.	Weight of whole crop (grms.).	Weight of grain (grms.).
Nil ...	41·4	18·7
Nitrate	69·8	20·8
Nitrate and phosphate	86·1	27·7

The chart No. 3 illustrates the same result. The same soil has been utilized for similar experiments during the current season, wheat being the crop, and the effect of phosphate is even more marked. The effect of potash was not tested in the rainy season of 1906, but judging by the present season's plants its effect will be negative.

Bangalore Soil.

This is derived from the laterite, and is consequently highly ferruginous. It holds only a low proportion of water. When wet, it drains readily, but at the same time contains so much plastic material, that it is adhesive when damp. The chief analytical data are :—

$CaCO_3$	·066
Total P_2O_5	·052
Available P_2O_5	**·0047**
Available K_2O	**·0023**
Organic Nitrogen	·059

Cultivations were made during three seasons, namely, the monsoons of 1904 and 1906 and the "cold weather" of 1904-05: the crops being Murwa (Eleusine coracana) in the former, wheat in the latter. The plants of the first two seasons were interfered with by the depredations of squirrels and rats, and ultimately the only dependable index of the effect of the manures was the estimated weight of green plants at the time the number of plants in each jar was reduced. It is clear that the phosphate had produced a positive effect at this time, and the cultivations of 1906, which were free from such errors as the above, leave no doubt of this. The effect of potash has been however much less certain, although one might have anticipated a positive result.

The weights of plants were as subjoined and the chart No. 4 refers to them also.

WEIGHT OF CROPS (GRMS.).

Manures.	1904 Murwa.	1904-05 Wheat.	1906 Murwa.
Nil	4·4	·51	10·6
Nitrate	4·15	1·66	39·1
Nitrate and phosphate ..	6·05	1·88	63·3
Nitrate, phosphate and potash	5·02	2·08	43·3

SHILLONG SOILS.

Two soils had been received from Shillong, the one being considered good, the other distinctly infertile. Examination in the chemical laboratory revealed nothing which would account for such a difference. Apart from other characteristics, they have proved to be very similar in their productive powers, and the difference noticed at the place of origin has not at any time exhibited itself in my experiments; both soils have proved to be very fertile. For purposes of differentiation their titles of "good" and "bad" have been retained. They are chiefly characterized by a high proportion of organic matter (3·09 per cent. organic

carbon) and great waterholding capacity. The chief analytical data are as follows :—

		"Good" soil.	"Bad" soil.
$CaCO_3$	...	·088	·025
Total P_2O_5	...	·069	·059
Available P_2O_5	..	**·011**	**·005**
Available K_2O	...	**·010**	**·012**
Organic Nitrogen +	...	·228	·193

Murwa was cultivated in the monsoons of 1904 and 1906, and wheat in the cold weather of 1904-5. Like the corresponding plants of the Bangalore soil, these suffered from attacks by rats when the wheat was ripening, and the only index remaining of the effect of the fertilisers was the estimated weight of the green plants when the number in each jar was reduced. The effect of phosphates in these soils is doubtful, whereas it should have been positive in both. This may in part be due to the absence of nitrogenous manure. In other experiments it has frequently been observed that, even though a soil is deficient in available phosphate, a positive effect of this plant food will only be realized if a nitrogenous fertilizer is added at the same time. In such cases, however, there was likewise a deficiency of nitrogen in the soil, and the combined effect of the fertilizers has been just what is found on similarly characterized plots at Rothamsted and Woburn. But when these pot cultures were commenced, the anticipation was that the Shillong soils were so well supplied with nitrogenous organic matter that added nitrate would have little or no effect, and with the limited amount of soil available the distribution of fertilizers was made on this basis. Later, after the effect of the "complete" fertilizer was observed, it was too late to re-arrange the treatment. For several reasons the most reliable result is that obtained in the new pot culture house at Pusa, and with that season's experiment phosphate had a distinctly positive effect. I consider it probable therefore that the indication provided by the analytical method in 1903 was correct and that phosphates would generally react positively with

this soil. The yields are as subjoined and are also illustrated by chart No. 5.

Shillong Soils.

Manures.	"Good." 1904 Murwa.	"Good." 1904-5 Wheat.	"Good." 1906 Murwa.	"Bad." 1904 Murwa.	"Bad." 1904-5 Wheat.	"Bad." 1906 Murwa.
			Weight of whole crop (grms.).			
Nil	52·2	·36*	31·8	42·5	·57*	32·4
Phosphate	40·1	·56*	33·7	50·0	·53*	41·8
Potash	57·5	·45*	43·2	49·5	·54*	31·1
Phosphate, potash and nitrate	74·7	·80*	69·1	56·2	1·06*	74·4
			Weight of grain (grms.).			
Nil	16·7		12·0	15·1	...	12·9
Phosphate	16·1	...	16·8	15·6	...	17·5
Potash	19·2		16·2	14·7	...	11·6
Phosphate potash and nitrate	30·0		26·5	19·7	...	28·6

* Estimated weight per plant on January 18th, 1905.

The Godavari Soils.

The soil of the Godavari Delta is largely black cotton soil of a very stiff tenacious type and is probably alluvium brought from the similar tracts of the Indian plateau. It was known that much of this land contained low proportions of lime and phosphate as determined in the laboratory, and sufficient earth was sent from two villages for three or four jars. But these portions contained rather more phosphate than was anticipated. The following are the analytical data :

	Vadlamur.	Ragampeta.
$CaCO_3$	·179	·134
Total P_2O_5 ...	·143	·119
Available P_2O_5	**·042**	**·011**
Available K_2O ...	**·010**	**·005**
Organic Nitrogen	·071	·084

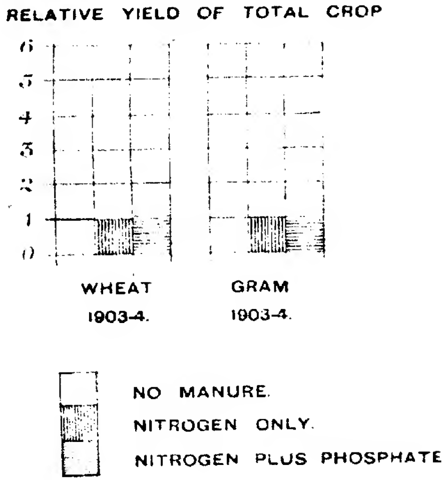
Cultivations were made during three seasons, and the yields are set out in the subjoined statement and on chart No. 6.

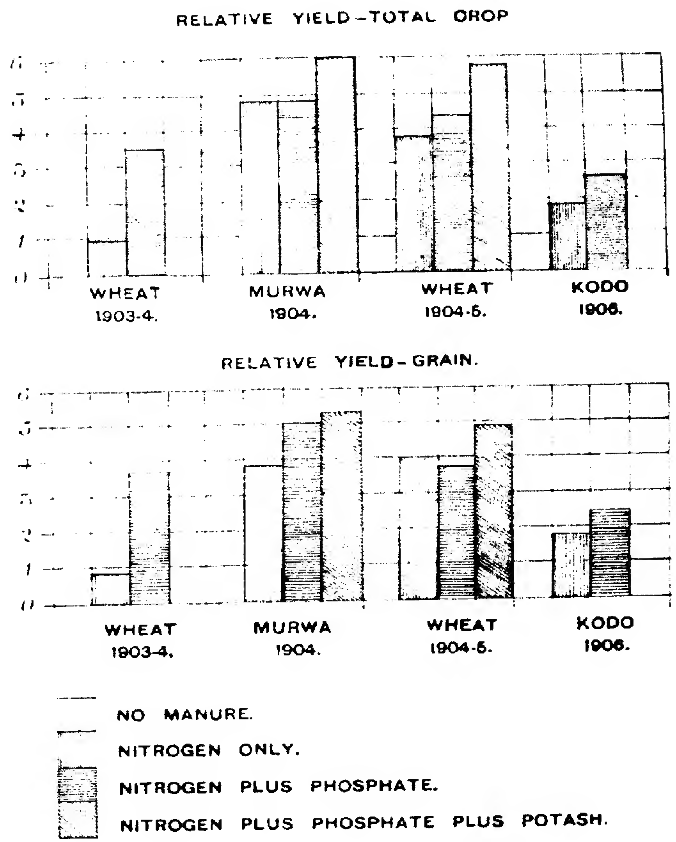
Godavari Soils.

Manures.	Vadlamur.			Ragampeta.		
	1904 Murwa	1904-5 Wheat.	1906 Murwa.	1904 Murwa.	1904-5 Wheat.	1906 Murwa.
	Weight of whole crop (grms.)					
Nitrate	45·8	18·9	57·0	32·4	22·0	66·4
Nitrate and phosphate	29·8	22·2	83·0	28·9	29·0	83·0
Nitrate, phosphate and potash	41·0	23·9	89·1	28·0	26·0	77·2
	Weight of grain (grms.).					
Nitrate	7·5	6·0	24·9	5·2	6·2	31·6
Nitrate and phosphate ...	5·9	5·2	37·4	7·1	5·7	38·5
Nitrate, phosphate and potash	6·0	4·0	39·0	6·2	5·5	31·1

These soils have given the least dependable data of any in the series; "Vadlamur" should hardly have given a positive reaction with phosphate; "Ragampeta" should have done so. As the data show, they have both reacted similarly, the first crop was negative, the second doubtfully positive, the third distinctly positive. The latter, grown under the much more satisfactory conditions at Pusa, is the most reliable.

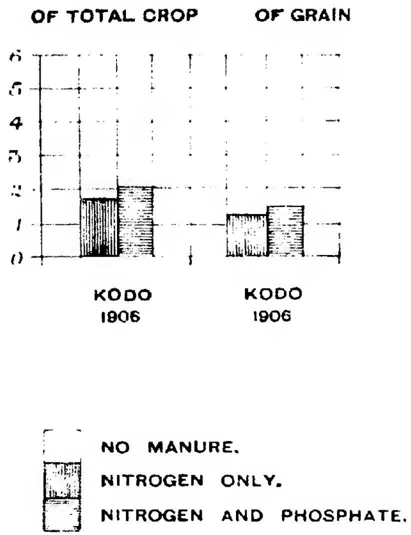
DEHRA DUN SOIL.





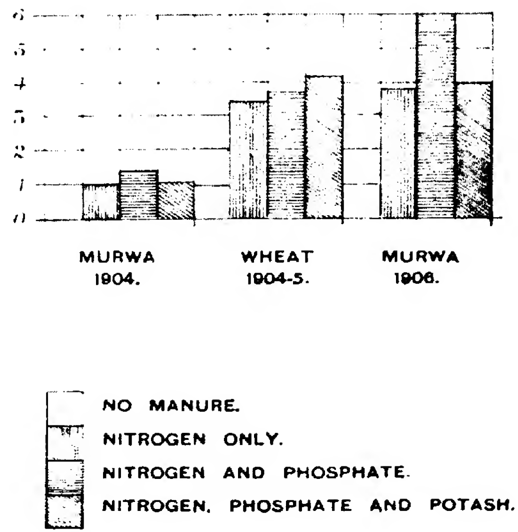
PUSA SOIL.

RELATIVE WEIGHTS

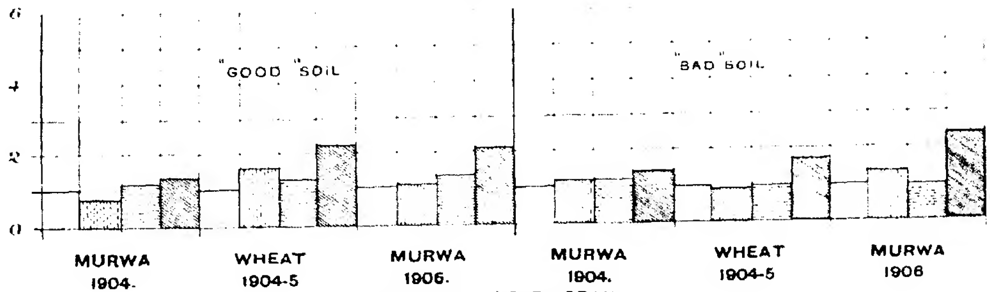


BANGALORE SOIL.

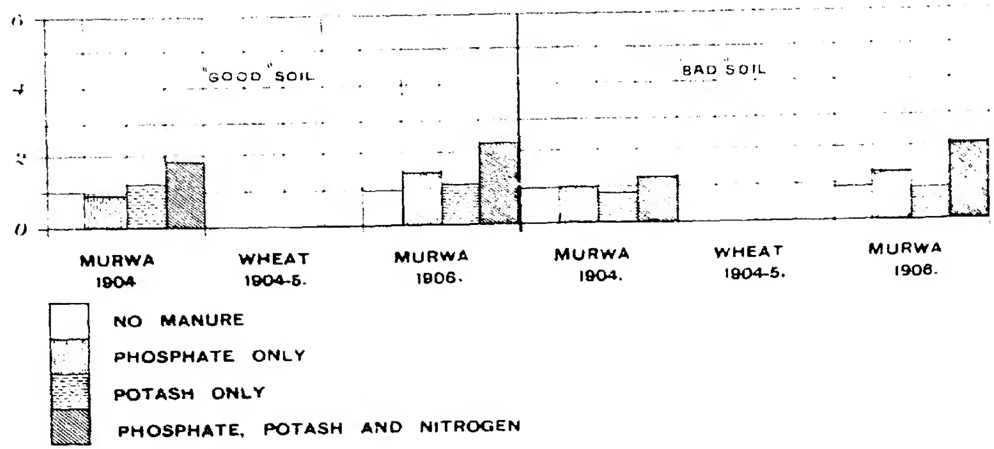
RELATIVE WEIGHT OF TOTAL CROP



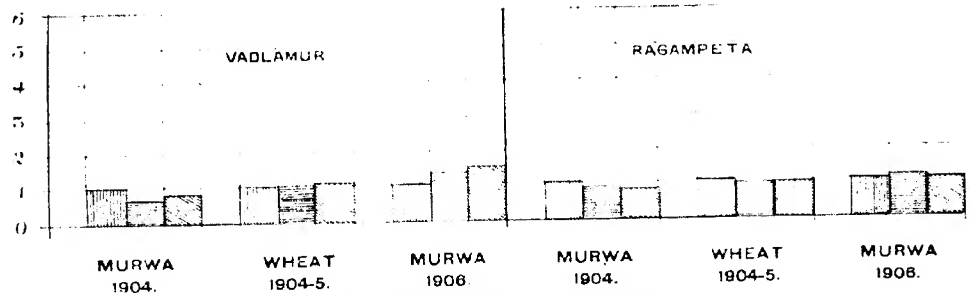
RELATIVE YIELD—TOTAL CROP.



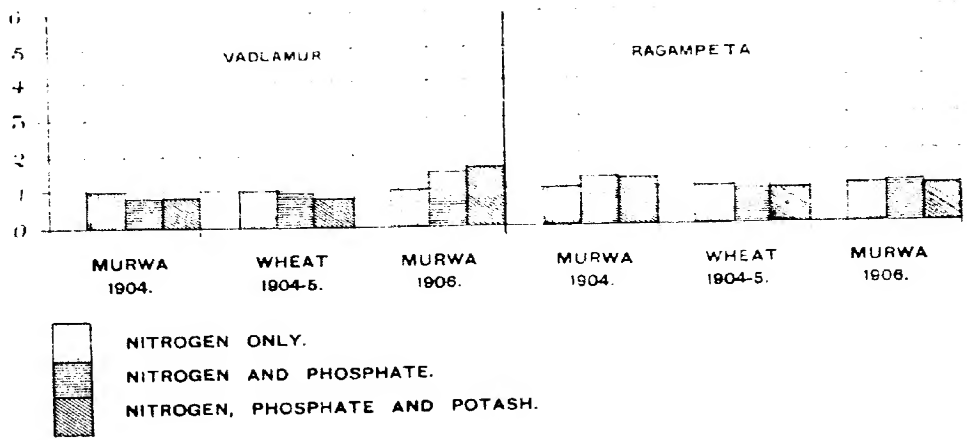
RELATIVE YIELD—GRAIN.



RELATIVE WEIGHT OF TOTAL CROP.



RELATIVE WEIGHT OF GRAIN.



PREFACE.

In this Memoir Mr. Arnott gives details of the cost of four drain gauges which have been constructed at Pusa. The detailed drawings and the photographs illustrate completely the method adopted.

It will be of interest if, to this description, is added a note of the principal uses to which these gauges may be put.

If such blocks of earth, as are referred to, are isolated, then the water which percolates through them during wet weather may be measured and compared with the rainfall: it may also be examined chemically. It is possible in this manner to obtain data regarding the following:—

(*a*) The amount of water which percolates per unit of time and its relation to the rainfall

(*b*) The amount of water flowing off the surface during storms.

(*c*) The proportion of the rainfall which evaporates.

(*d*) The effect which growing plants exert on these proportions.

(*e*) The amount of any plant foods which pass away in such drainage water.

The most complete records which have been maintained in other countries on this subject are those at Rothamsted, which extend over a period of 30 years, and admit of the following deductions being drawn:—

(1) The amount of percolation in any year varies directly with the rainfall; thus with a rainfall of 41 inches the percolation was about 25 inches, with a rainfall of 19·5 inches percolation was 6 inches.

(2) The amount of evaporation is very nearly constant, and is slightly greater in wet years than in dry ; thus in the two years referred to, with a rainfall of 41 inches the evaporation was about 16 inches, whilst with the rainfall of 19·5 inches the evaporation was about 13 inches. This is the opposite of what is usually supposed and is probably due to the fact that the greater part of the evaporation occurs immediately after rain.

Regarding these two points we have a certain amount of information also in India. Four gauges were constructed at Cawnpore in 1903, and the four years' data go to show very clearly that the conclusion arrived at from the Rothamsted gauges will be confirmed here also. The following statement embodies the chief items relating to this part of the subject :—

Period.	Rainfall.	Percolation.	Overflow.	Evaporation.
June 1903—October 1903 ...	26·14	11·55	*Nil.*	14·59
October 1903—October 1904 ...	45·66	25·58	4·0	16·08
October 1904—October 1905 ...	20·62	3·03	*Nil.*	17·59
October 1905—October 1906 ...	36·50	18·72	*Nil.*	17·78

It will be seen that (*a*) the amount of percolation varies directly with the rainfall ; (*b*) the amount of evaporation is fairly constant.

Regarding the surface flow during storms, provision is scarcely necessary for this in Europe where nearly the whole of the rainfall is absorbed by the land directly. In India it is clear that during heavy falls of rain which are so common, some water flows off the land. The Pusa gauges have been provided with means of measuring the amount of this overflow of storm water

In reference to the composition of the drain-gauge water, the chief factor which is being recorded at Rothamsted is the amount of nitrate Those gauges are kept free from vegetation and the quantity of nitrate which has been carried away is equal to about 30 lbs. of nitrogen per acre per annum. The Cawnpore gauges have yielded very much larger amounts of nitrate ; this

soil had been heavily manured for some years previous to the construction of the gauges, and this large amount of nitrate is no doubt readily accounted for in this manner. The gauges at Pusa have been made in land which has not been either cultivated or heavily manured for a long time, and the amount of nitrate present in the drainage water last year was very small.

The effect of plants growing on such gauges would be undoubtedly to use up much of the water and plant food which percolates in the absence of vegetation. How great this effect is, has so far been ascertained in only a very general way; the intention is, however, to grow crops and grass on some of the Pusa gauges and so obtain data in this direction also.

There can be no doubt that information obtained by drain gauges is of very great importance, especially in India where practically nothing is known at present of what becomes of the rain which falls on the land, and observations by means of them in different places is highly desirable.

J. WALTER LEATHER.

PUSA;
July 1907.

THE CONSTRUCTION OF DRAIN GAUGES AT PUSA.

BY

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Superintending Engineer, P. W. D.

IT has been thought that a paper detailing the construction of the drain gauges lately made at Pusa might prove of use in case others at any time may have to be constructed, and as they were built under the writer's supervision, he has been asked by Dr. Leather, Imperial Agricultural Chemist, to write such a paper. The problem to solve was to cut out from the original soil an irregular cube of earth 7 ft. 4 in. long by 6 ft. broad and 6 ft. or 3 ft. deep, support it and enclose it with masonry walls and in so doing prevent any cracks from occurring. The existence of cracks would make the gauge useless, so the problem was one of considerable practical difficulty. After a good deal of consideration and discussion it was determined that the best way to do the work was to make an experimental gauge on the following lines :—

(i) To cut a trench some 12 or 13 ft. deep on both sides of the irregular cube, as shown in Plate I, finely dressing the sides of the earth between the two trenches where the gauge was to be, (ii) to make holes as shown in Plate No. II right through the thickness of the gauge, and (iii) into which would be inserted mild steel joists, supported as shown in Plate No. III; (iv) having inserted the joists and supported them on both sides, to "jack" in mild steel plates between the top of the joist and the earth,

operating from both sides of the gauge. If the plates could be got home by means of the screw jacks so that the whole of the superincumbent earth was supported, and this without cracking the soil or tearing away portions of it, the problem was practically solved, for the rest of the operations required only very careful treatment.

It would have been impossible to have got one plate 8 ft. 7 in. by 9 ft. 2 in. into position over the joists owing to its excessive weight, so the writer settled to use six plates as shown in Plate XVIII. The experimental gauge showed that this could be done, and three plates having been successfully placed in position, further operations were stopped and work was commenced on the four gauges that had to be built, two with a 6-ft. and two with a 3-ft. depth of earth. Before describing the construction in detail, it will be of interest to describe a completed drain gauge and to note the calculations necessary for arriving at the proper sections for the mild steel joists, their number, thickness of plates, etc.

Description of a 6-ft. Drain Gauge.

As has been mentioned before, the earthen gauge is to be surrounded by masonry for a depth of 6 ft. or 3 ft. Below this depth, three of the masonry walls only are carried down, but the fourth wall stops at plate level so as to allow entry into this underground chamber in which the drums for collecting water are to be placed, and the amount so collected read off by the observer. This means that on this fourth side the joists and plates must be supported by a bressummer which in its turn is supported by the two side walls as will be noticed in Fig. 2, Plate IV. Plates IV and IV[1] show plan and sectional elevations of a 6-ft. gauge Below this bressummer it was settled that a 6-ft. space to concrete floor level would be sufficient, making a total height of 13 ft. 2½ in. from ground level. To get down to the chamber, a well, provided with a fixed ladder, was made as shown in Fig. 3, Plate IV[1], and to prevent rain water getting in, the top of the well is provided with

two corrugated iron half doors. It would have been better to have used flat iron plates as doors as it has been found that frogs enter, owing to the folds in the former, die in the well and have to be removed. The plates placed above the joists are perforated with half inch diameter holes, six inches apart from centre to centre, over the whole superficial area of 7 ft 4 in. by 6 ft 0 in. or $\frac{1}{1000}$th of an acre. The water coming through the perforated plates is collected by means of a collecting plate with a funnel, made of galvanized sheet iron, a plan of which is shown in Fig. 4, Plate IV[1]. This is fixed into the walls with a slope from back to front and the method of attachment is depicted in Fig. 5, Plate IV[1]. Fig 6, Plate IV[1], is a mud hole in the collecting plate so that the space between it and the perforated plates may be cleaned out at any time. The drain gauge chamber, in which the drums are placed, is also provided with a corrugated iron door and its three walls are all buttressed as explained further on. In order to render the floor as it was hoped, water-tight, 2-in. stone flagging was placed above the concrete floor, but still the water comes up to a depth of 1 in. through the junction between the stone. This has been found from the experience of this year's rains. It will be necessary to cover the whole floor with a further thickness of 1 in. Indian Patent Stone, which should have the desired effect. It is imperative that no water should be able to percolate from the outside of the masonry into the gauge, as this would vitiate the whole of the results, so between the sides of the earthen cube and the brick work, 3 in. of cement concrete is provided. This is shown in Figs. 2 and 3, Plates IV and IV[1]; in Plate No. V this small edging of concrete between the brickwork and earth may be noticed. In addition the whole of the brickwork inside and outside is cement plastered. The masonry walls are carried 5 in above the ground surface of the drain and are made to slope outwards. In one wall are placed three one-inch overflow pipes, two three and four inches, respectively above ground level, and leading into a small overflow chamber 3 ft. 5 in. by 3 ft. 5 in. and 2 ft. in depth. Each pipe is provided with a cock. The above is shown in Plate No. VI.

Calculations necessary to determine the Dimensions of the Joists, Plates, Thickness of Walls, etc.

The bressummer joist bears half the weight of the earth, the cross joists and the plates, and the front portion of the masonry, and, as is seen by the calculations in Appendix A, a joist of 9 in. by 4 in. is sufficiently strong for the load it has to carry.

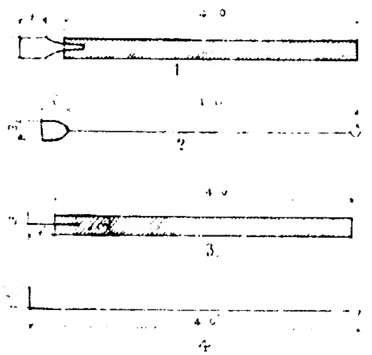
The cross joists bear the weight of the earth and the weight of the plates. Five joists were used so that the space between each joist might be 1 ft. 9 in., this space being regulated by the size of the plates To have had fewer joists would have meant a greater distance between each joist and therefore bigger and consequently heavier plates, for it is essential that the plates must have their ends resting on the joists as is seen in Plate VII. The calculations in Appendix B show that joists 5 in. by 3 in. are strong enough. The perforated plates are ½ in. thick according to the calculations in Appendix C; this thickness is far in excess of requirements, but owing to the numerous perforations, the strength of the plates is considerably reduced, so for safety's sake ½ in. plates were used. The pressure on the foundations was taken at 0·7 of a ton per sq. ft., the permissible for Bengal being 1 ton per sq. ft. ; the calculations are given in Appendix D. The calculations for the joists and plates are based on the commonest case in Applied Mechanics of a beam supported at the both ends and loaded throughout its length with an evenly distributed load.

During the construction of the walls it struck the writer to see if the earth pressure rendered the structure unstable and it was found that the centre of pressure fell outside the base, so it was necessary to buttress the three walls. The calculations are given in Appendix E.

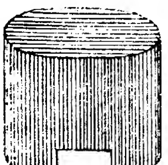
Construction of a 6-ft. Drain Gauge.

It would not have been safe to have cut the trenches out as shown in Plate I so as to have left exactly 6 ft. of earth between them, as this would allow of no margin for any small accidents that might occur, such as, say, 3 inches of soil falling away from

he face, so the dimensions of the drain gauge, as already noted, eing 7 ft. 4 in by 6 ft., an area of 8 ft. 10 in. by 7 ft. 6 in. was pegged out by means of the theodolite, thus leaving a 9 in. margin on each side. The two trenches on both sides of the 7 ft. 6 in. breadth were then excavated to a depth of 13 ft. and for a length of 17 ft. As the work descended, a ramp was made on both sides. The two faces of the gauge were then very finely and carefully dressed by the masons and the positions of the joists marked on them. The vertical distance from ground level to the top of the joist was 6 ft. 0½ in., and each joist was to be 1 ft. 9 in., centre to centre, from the other, so their positions were easily fixed. The five joist holes 1 ft. square had then to be drilled through the 7 ft. 6 in. length, and this had to be done by masons and not by coolies. For the purpose, the four tools, of which sketches are given below, were used.



No. (1) is used for digging out the holes, No. (2) for dressing the four angles of the holes, No. (3) is used for dressing the top surface of the holes roughly horizontal, and No. (4) for making the same truly horizontal. Plate II shows how accurately this work was done by the masons. After the joists have been inserted into the holes, Plate II, they are supported as shown in Plate III, that is, by two 2-inch "sal" boards. These boards rest on props, the lower ends of which lie on another 2 in. "sal" board, and this latter rests on ground that has been thoroughly rammed and consolidated to obviate any chance of settlement when the full load comes on. A groove, as in sketch, is made in the lower end of the props into which wedges are inserted and driven home so as to ensure that the upper ends of the props are really pressing against



the "sal" boards. Plates VIII and IX show geometrically the holes and the joists inserted, Plate X the joists propped and the structure ready for the insertion of the plates. Plates VII and XI show the plates supported, and the jacks in position. The operation is commenced from one end, and when one plate is driven in, the opposite plate on the other side is next jacked in, and so on until the whole six plates are fixed *in situ*.

The secret of success is, firstly to see that each plate during the operation is kept perfectly horizontal, both longitudinally and transversely, and for this purpose frequent use must be made of the spirit level; secondly, that the levers of the two jacks are invariably turned simultaneously and for the same distance, so that the plate may be driven in evenly. To ensure this, after every turn of the jacks, the distance between the edges of the plates and the edges of the joists on which it rests, must be measured to see that they agree. If there is any difference, this must be adjusted by turning one jack and not the other. After the plate is in position and properly levelled and tightened up by the screw jacks, before they are turned a piece of earth six inches in thickness is removed from underneath the joist to a depth of about 1 ft. 6 in. just sufficient, eventually to allow a man to crouch in and remove the earth for half-an-inch above the joists. This is done by means of the scraper of the shape shown in sketch 3 in the previous paragraph. The cutting out of this half inch is done carefully and as truly level as possible. After the plates have been driven in this six inches, another six inches is removed in similar fashion, and this goes on till the plate is jacked home. When two opposite plates are getting close together, the screw jacks must be turned very gently, for the plates must not be allowed to touch each other and a clearance of a quarter-of-an-inch is left. In pushing in the plates should one abut against the other, it will set up, at the time of contact, great internal vibration in the block and most likely produce cracks or cause portions of the block to shear off. This was noted in the experimental gauge. When all the plates are in position, it is necessary to test whether the earth is everywhere resting evenly on them, and this can be done by measuring the depth from the

bottom of the earth to the bottom of the plates by means of the perforations in the latter. If this depth is more than half an inch, it shows that the plates are not pressing up against the earth and they must be wedged up with iron wedges, placed between the bottom of the plates and the top of the joists, so that they may do so. For making the joist holes, placing the joist in position and propping them, 1 head mason, 4 masons and 6 coolies will do the work in two days, and the same number of men in the same time will completely drive the plates home as soon as they get a little experienced. Unless the placing of the plates under the gauge is most carefully supervised by an Engineer and not left for a single moment to the masons, the operation will be a failure, so unless an entirely reliable man's whole time can be given up to this, it is better not to attempt it. After the plates are in, the rest of the earth is removed to the required depth and the joists and plates are further shored up by three rows of "sal" props in the same manner as was described for the end props. This shoring is shown in Plate XII. The whole of the gauge being now supported, the props at the back are removed, the foundations of the back wall dug, concrete laid and consolidated, and after it has set, the back masonry wall is constructed to the bottom of the joists, they resting securely on the masonry by means of $\frac{3}{4}$in. bed plates. The front row of props is then removed and the bressummer joist placed in position and kept there by bamboo props, care being taken to see that the joist is exactly level. After this has been done, the two open sides of the gauge are supported horizontally to prevent any lateral displacement, the earth on the uncut sides is then excavated to proper depth, the supports to the first two sides removed temporarily and the whole gauge brought to its proper dimensions, namely, 7 ft. 4 in. by 6 ft. 0 in., by fine dressing by the masons. Plate XIII shows this operation completed. The gauge is again shored in the manner depicted in Plates XIV and XV. Plates XVI and XVII also show the same treatment for one of the 3-ft. gauges ; here, as the soil was more friable, close shoring was resorted to. The brickwork of the remaining walls is then proceeded with, till eventually the whole gauge is enclosed

in masonry as is seen in Plate V. This having been successfully accomplished, the rest of the construction calls for no detailed description. It consists in simply building the floor of the chamber, fixing the collecting plate, building up the well and the ladder at the same time, fixing the doors and constructing the overflow reservoir. Great care should be taken to see that the masonry is as well made as possible, all joints being thoroughly filled up with mortar, and still more care should be taken at all junctions. The filling of the trenches also requires attention, and the earth should be rammed in six-inch layers.

Cost of a 6-ft. Drain Gauge.

The total cost of a 6-ft. Drain Gauge as actually constructed comes to Rs. 1,138 with the rates that obtain at Pusa. In Appendix F is given an abstract of the expense showing the quantities or numbers of each sub-head, its rate and cost.

APPENDIX A.

Calculation for determining the size of the Bressummer Joist.

Bressummer joist at entrance

Total load on this beam

$$= \frac{\text{wt. of earth}}{2} + \text{wt. of top portion of the masonry} + \frac{\text{wt. of plate}}{2} + \frac{\text{wt. of 5 joists}}{2}$$

$$= (7'\ 4'' \times \tfrac{6}{2} \times 120 \times 6'\ 0'' + 7'\ 4'' \times 1'\ 6'' \times 120 \times 6'\ 0'') + (4'\ 6'' \times 7'\ 4'' \times 20) + (5 \times 4'\ 6'' \times 11) \text{ lbs}$$

$= 23{,}760 + 660 + 247$ lbs.

$= 24{,}667$ lbs.

$$Mr = \frac{Wl}{8} = \frac{24{,}667 \times 7 \times 12}{112 \times 20 \times 8} = 115{\cdot}6 \text{ inch tons.}$$

Take a section 9″ × 4″ @ 21 lbs.

$$Mr = \frac{P \times I}{y} = \frac{7{\cdot}5 \times 81{\cdot}52}{4{\cdot}5} = 135{\cdot}8 \text{ inch tons.}$$

So this section may be used leaving a good margin of safety.

APPENDIX B.

Calculation for determining the size of Cross Joists.

$$Mf = \frac{W\ l}{8}$$

$$= \frac{6'\ 11'' \times 12\ (1 \cdot 75 \times 6'\ 11'' \times 6'\ 0'' \times 120 + 6'\ 11'' \times 1 \cdot 75 \times 20)}{8 \times 112 \times 20}$$

$= 41 \cdot 4$ inch tons.

Take a section $5'' \times 3''$ @ 11 lbs.

whose $Mr = \frac{P \times I}{y} = \frac{7 \cdot 5 \times 13 \cdot 69}{2 \cdot 5} = 41 \cdot 07$ inch tons.

So this section may be used.

APPENDIX C.

Calculation for determining the thickness of Mild Steel Plate.

Take a strip 1 foot say. The load on this strip

$= 1 \cdot 75 \times 1 \times 6\ \ 0'' \times 120$ lbs.

$$Mf = \frac{1 \times 1 \cdot 75 \times 6 \times 120 \times 24}{8 \times 112 \times 20}$$

$= 1 \cdot 5$ inch tons.

Take a section $\frac{1}{2}''$ thick.

$$Mr = \frac{P \times I}{y} \qquad I = \tfrac{1}{12}\ bd^3.$$

$$= \tfrac{1}{12} \times 12 \times \cdot 5 \times \cdot 5 \times \cdot 5$$

$$= \cdot 125$$

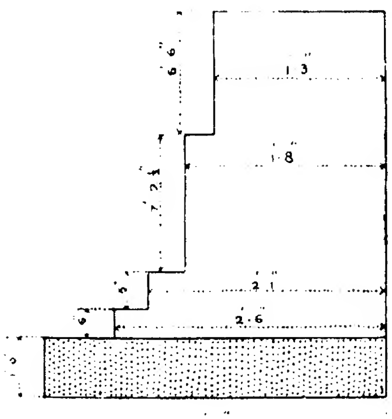
$$= \frac{7 \cdot 5 \times \cdot 125}{\cdot 25} = 3 \cdot 75 \text{ inch tons.}$$

APPENDIX D.

Calculation to ascertain the thickness of the Foundations.

THE walls are to be built first and they will bear the full load before the buttresses can be constructed, as the props cannot be removed. The whole weight, therefore, falls on the base of the walls. The buttresses merely help to resist the earth pressure when the filling is completed. The walls are in consequence designed to bear the superincumbent weight of earth and masonry independently of the buttresses.

EXTREME CASE TAKEN.



Wt. of masonry

1 × 6′ 6″ × 1′ 3″ = 8·12
1 × 7′ $2\frac{1}{2}$″ × 1′ 8″ = 12·00
1 × 0′ 6″ × 2′ 1″ = 1·04
1 × 0′ 6″ × 2′ 6″ = 1·25
1 × 3′ 6″ × 1′ 0″ = 3·50
= 25·91

Wt. of earth

1 × 3′ 3″ × 6′ 0″ = 19·50
= 45·41

$\frac{45·41 \times 120}{112}$ cwts.

= 48·65 cwts.
= 2·43 tons.

Pressure = $\frac{2·43}{3·5}$ = 7 tons nearly which may be allowed as the soil below 15′ 0″ is softer than the top soil.

The earth pressure is obtained from the formula :—

$$P = \frac{w\ H^2}{2} \times \frac{1 - \text{Sin}\,\alpha}{1 + \text{Sin}\,\alpha}$$ where α = angle of repose of the soil.

In this case taken at 54° as it is moist earth.

$$= \frac{120 \times 13{\cdot}20 \times 13{\cdot}20}{2 \times 112{\cdot}} \times \frac{1 - {\cdot}80}{1 + {\cdot}80}$$

$= 10{\cdot}26$ cwt. $= {\cdot}5$ tons.

The earth pressure acts at ⅔rds the height of the wall and is horizontal. The diagonal of the parallelogram in Plate XIX is the resultant of the two forces, and is seen to fall outside the wall. This shows that the wall is unstable when the earth pressure exerts its full force. To make it stable a buttress is necessary.

The following are the calculations after adding in the buttress :—

There are now three parallel forces, the centres of gravity of which act at different points.

The forces are :—

(i) the weight of the top block of masonry

$= 1 \times 6'\ 6'' \times 1'3'' = 8{\cdot}12 \times \frac{120}{112} = 8{\cdot}70 = {\cdot}43$ ton.

The centre of gravity of this passes through the middle of the 1′ 3″ wall.

(ii) The weight of earth $= 1 \times 3'\ 3'' \times 6'\ 0'' = 19{\cdot}50 \times \frac{120}{112} =$ 1 ton.

The centre of gravity of this passes through the centre of the 1′ 8″ wall.

(iii) The weight of the bottom portion of masonry after adding the buttress :

This is taken as a trapezium.

$$1 \times \frac{1'\ 8'' + 4'\ 1''}{2} \times 7'\ 2\tfrac{1}{2}'' \times \tfrac{120}{112} = 22{\cdot}14 = 1{\cdot}1 \text{ ton.}$$

The centre of gravity of this has been worked out graphically, see Plate XX.

There are now three like parallel forces and their resultant is equal to 2·53 tons.

The point of application of the resultant is found diagrammatically. Plate XX.

The main component forces have now been ascertained, namely, the pressure of earth acting at ⅔rds the height of the wall and the resultant of all the vertical pressures. The resultant of these two forces is also ascertained as in the first case by drawing a parallelogram with a scale of load of 1 ton = 1″

This resultant falls within the middle third of the base which shows that the structure is stable.

APPENDIX E.

Calculation to determine if the walls require Buttresses or not.

THE weight of earth and superstructure masonry are as follows :—

Weight of top portion $= 1 \times 6'\ 6'' \times 1'\ 3'' = \dfrac{8{\cdot}12 \times 120}{112}$

$= 8{\cdot}70$ cwt.

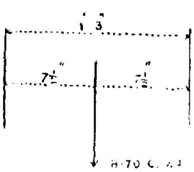
Weight of bottom portion $1 \times 7'\ 2\tfrac{1}{2}'' \times 1'\ 8'' = 12{\cdot}00$ „

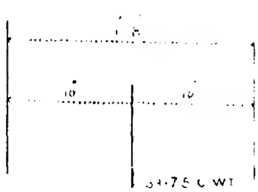
Weight of earth $= 1 \times 3'\ 3'' \times 6'\ 0'' = \underline{19{\cdot}50}$ „

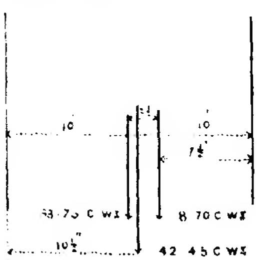
$31{\cdot}50 \times \frac{120}{112}$

$= 33{\cdot}75$ cwt.

The centre of gravity of the top portion passes through the middle of the 1′ 3″ wall and the centre of gravity of the bottom portion together with the weight of earth passes through the middle of the 1′ 8″ wall. Now there are two like forces acting at different points of the same wall. The magnitude of the resultant will therefore be equal to their sum $= 42{\cdot}45$ cwt. $= 2{\cdot}12$ tons, and the point of application is $10\frac{1}{2}''$ from the outer face of the wall, thus :—







The distance between the points of application of the two forces is $2\frac{1}{2}''$. Let x be the distance of the resultant from the first force, then we have $33{\cdot}75\,x = 8{\cdot}70\ (2{\cdot}5 = x)$ from which we get $x = \frac{1}{2}''$: therefore the resultant is situated $10\frac{1}{2}''$ from the outer face.

APPENDIX F

Details of cost of a 6-foot Drain Gauge.

Quantity or No.	Abstract of expense.	Rate. Rs.	As.	P.	Per	Amount. Rs.	TOTAL. Rs.
1. 5,230 c. ft.	Earthwork in excavation	5	0	0	0/00	26	
2. 3,356 c. ft.	Earthwork in filling	2	0	0	0/00	7	
3. 1 set.	Extra labour for pushing in the bed plates ...	45	0	0	L. S.	45	
4. 170 c. ft.	Concrete in foundation with lime mortar	18	0	0	%	31	
5. 127 c. ft.	Extra cement in concrete for foundations	2	0	0	%	3	
6. 1,241 c. ft.	Brick in lime	23	0	0	%	285	
7. 506 s. ft.	Cement plaster, ½″ thick	6	0	0	%	30	
8. 143 s. ft.	Cement plaster, ¾″ thick	12	0	0	%	17	
9. 38 s. ft.	2″ Sand stone flagging	35	0	0	%	13	
10. 15·49 cwt.	⅜″ Mild steel plate	11	8	0	cwt.	178	
11. 1·5 cwt.	½″ Wrought iron bed plate	11	0	0	cwt.	17	
12. 1 set.	Fixing in the bed plates	1	0	0	L. S.	1	
13. 6·45 cwt.	Mild steel joists	8	12	0	cwt.	57	
14. 41·5 c. ft.	Cement concrete	55	0	0	%	23	
15. 168 Nos.	Making holes in plate	0	3	0	each	32	
16. 1 set.	Coal tarring and painting to joists	2	0	0	L. S.	2	
17. 1·33 cwt.	W. I. work in ladders	15	0	0	cwt.	20	
18. 54 s. ft.	Corrugated iron doors, including fastening arrangements	0	10	0	s. ft.	34	
19. 140 r. ft.	6″ diameter sal ballah props	0	5	0	r. ft.	41	
20. 1 set.	Extra labour for cutting the sloped bricks at top	2	0	0	L. S.	2	
21. 1 set.	Extra labour for cutting the sloped bricks of buttress	4	0	0	L. S.	4	
22. 1 set.	Painting the plates, etc., with Bitumastic solution	8	0	0	L. S.	8	
23. 19·5 r. ft.	1″ diameter W. I. pipes	0	6	0	r. ft.	7	
24. 3 Nos.	1″ brass plug cocks	6	0	0	each	18	
25. 2 Nos.	Galvanized iron drums complete	45	0	0	each	90	
26. 1 No.	⅛″ thick plain galvanized sheet iron rain collector and funnel	90	0	0	each	90	
							1,084
	Add contingencies at 5%						54
	TOTAL	...				...	1,138
	A 3 foot Drain Gauge cost Rs. 1,069.						

PLATE No. I

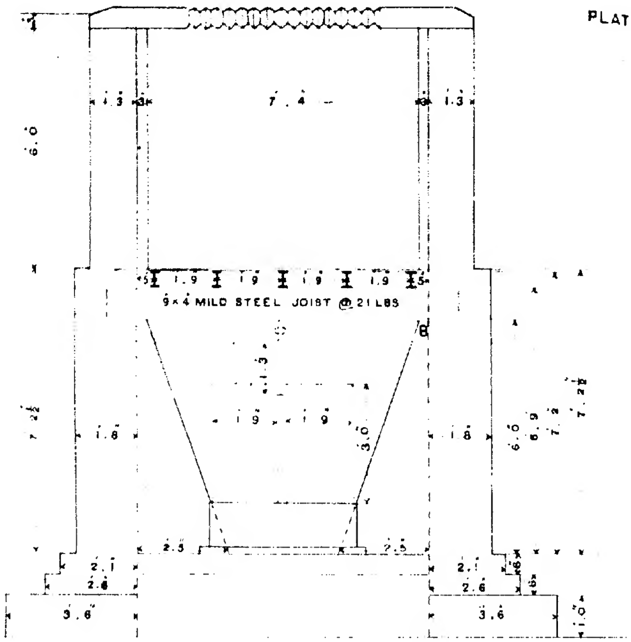
PLATE No II

PLATE No. III

SECTION ON C.D.

SCALE 4FT=1 INCH

PLATE I



PLAN

FIG: I

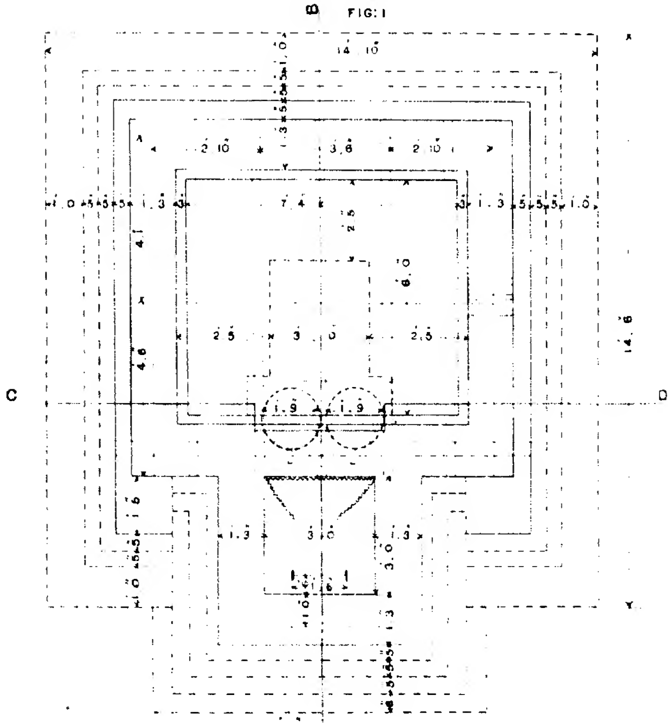


PLATE IV[1]

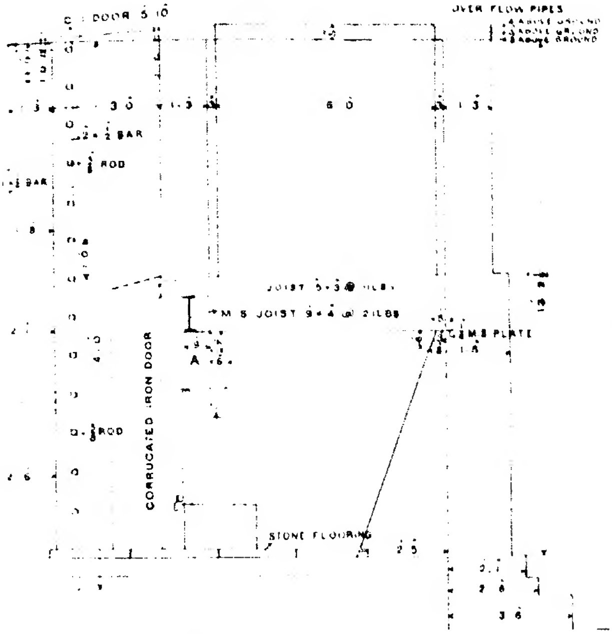


FIG: 3
SECTION ON A B
SCALE 4=1

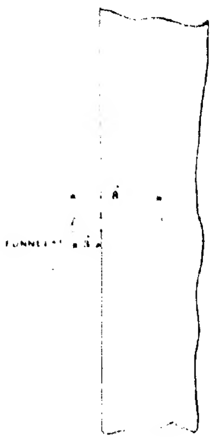


FIG: 5
DETAIL AT B

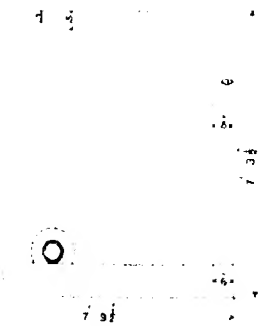


FIG: 4
PLAN OF FUNNEL

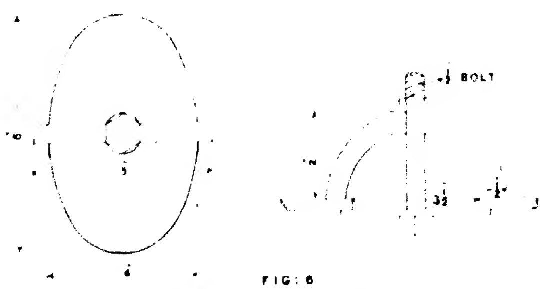


FIG: 6
DETAIL AT A OF MUD HOLE PLUG
SCALE ½ FULL SIZE

PLATE No V

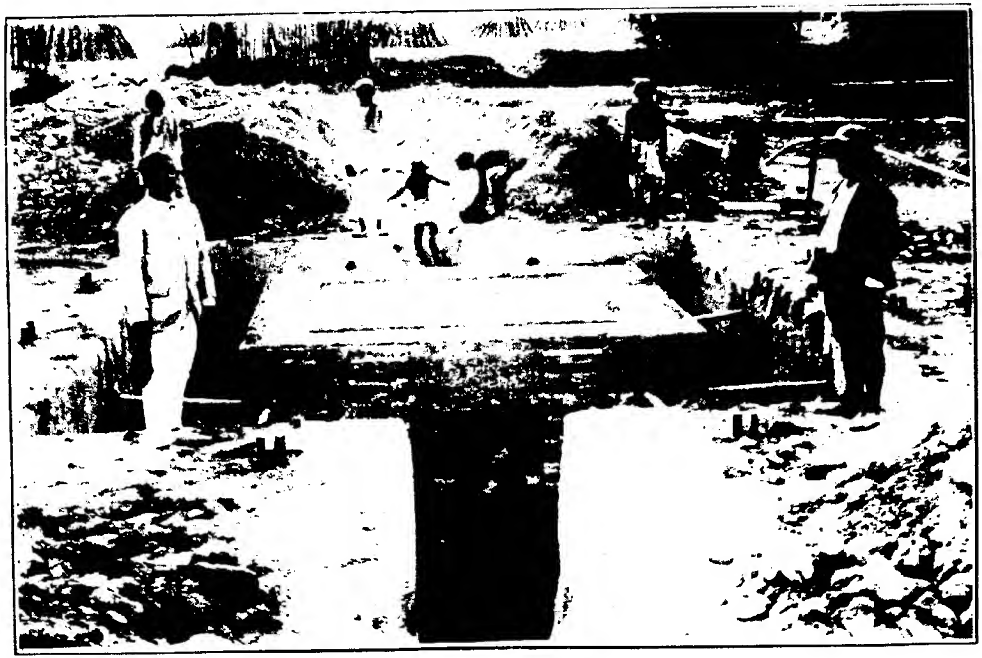
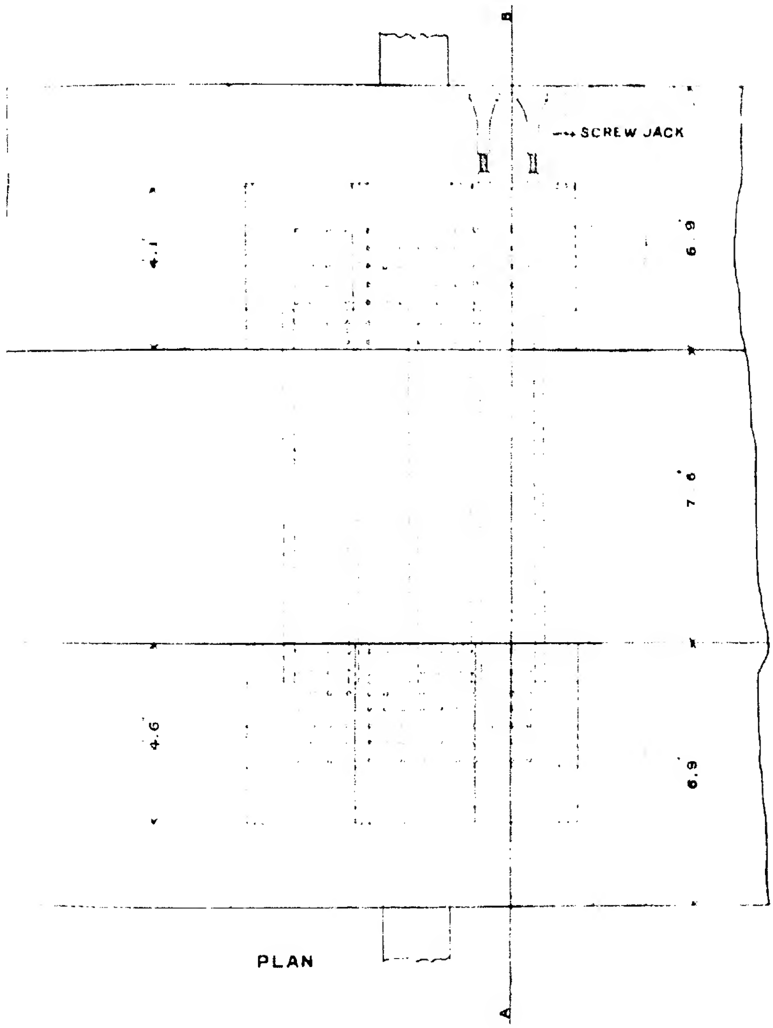


PLATE No VI

PLATE VII

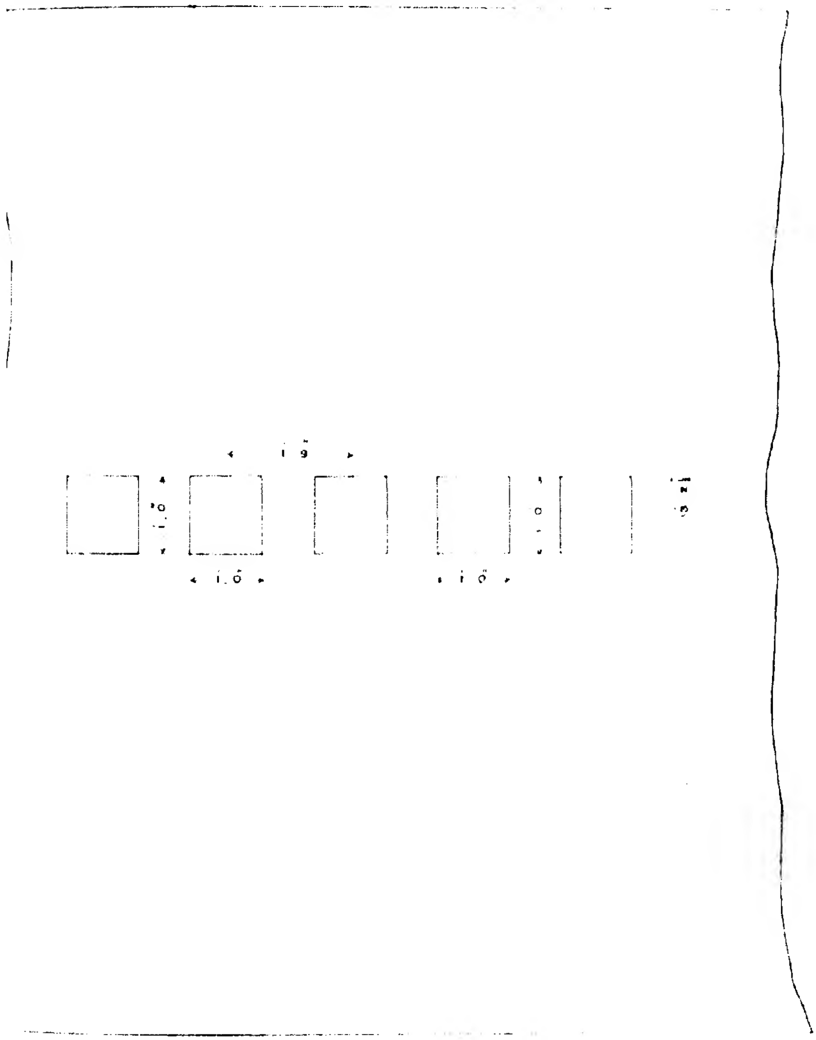
SHOWING PLATES IN POSITION AND ABOUT TO BE PUSHED HOME WITH THE SCREW JACKS

SCALE 4 FEET=1 INCH.



PLAN

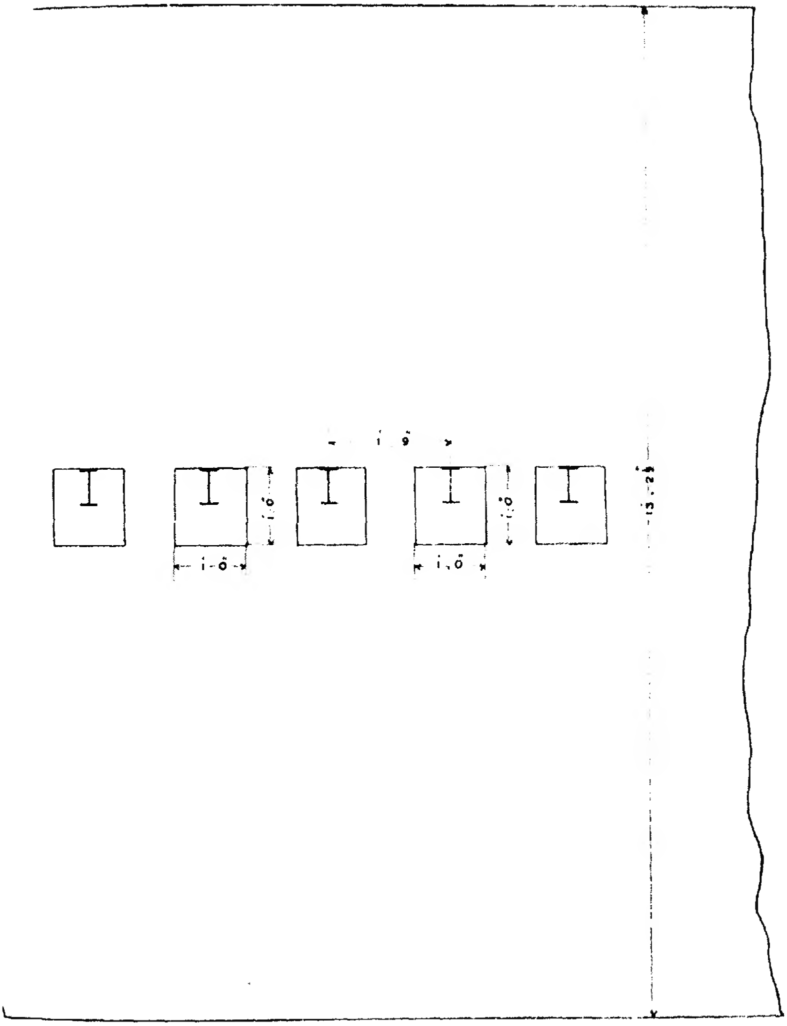
DIMENSIONED SKETCH SHOWING JOIST HOLES.
SCALE 2 FEET = 1 INCH.



ELEVATION FROM ONE FACE.

PLATE IX

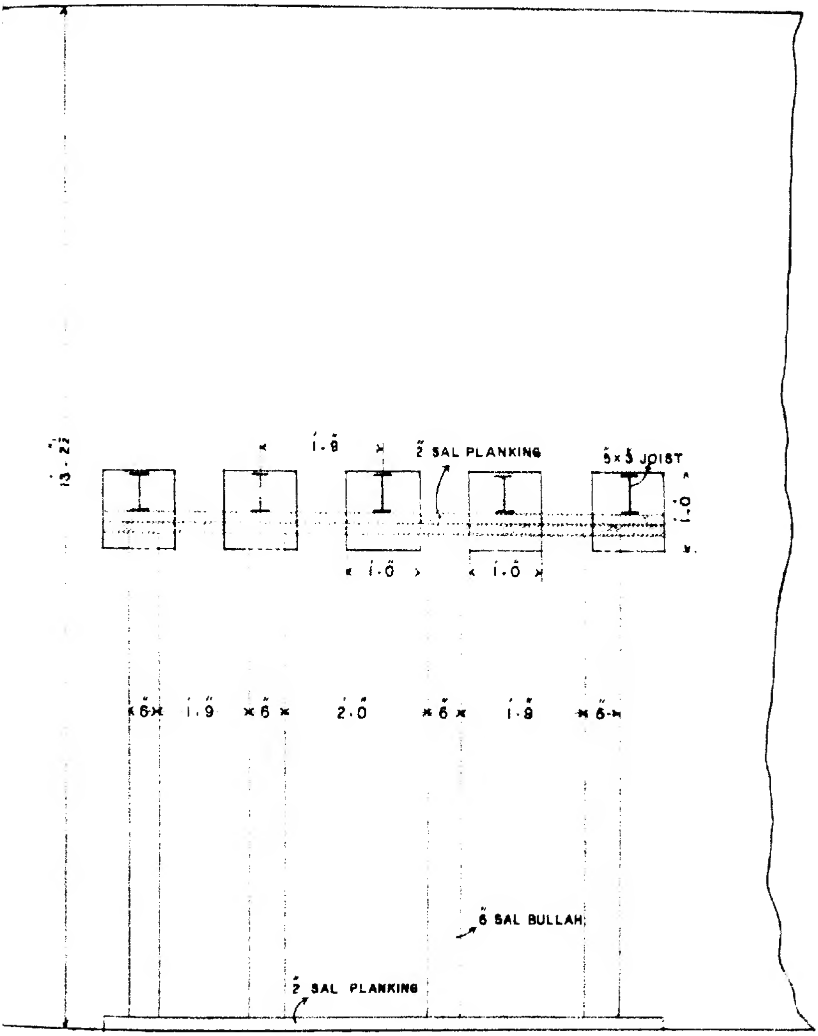
DIMENSIONED SKETCH SHOWING JOISTS IN POSITION.
SCALE 2 FEET = 1 INCH.



ELEVATION FROM ONE FACE.

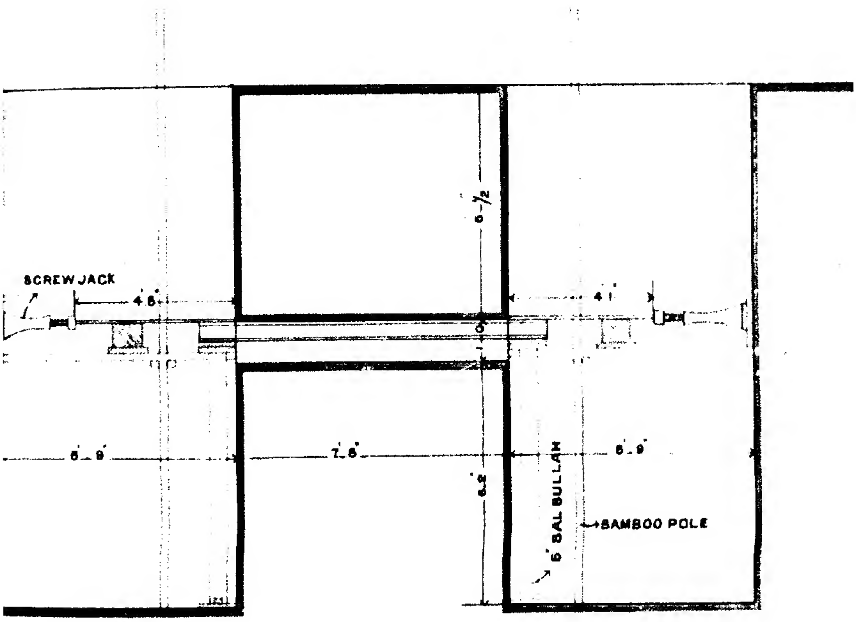
PLATE X.

IMENSIONED SKETCH SHOWING JOISTS PROPPED BEFORE INSERTING THE PLATES.
SCALE 2 FT. = 1 INCH.



ELEVATION FROM ONE FACE.

DRAWING SHOWING PLATES IN POSITION AND ABOUT
TO BE PUSHED HOME WITH THE SCREW JACKS
SCALE 4 FEET = 1 INCH.



SECTION ON A.B.

PLATE No XII

PLATE NO. XIII.

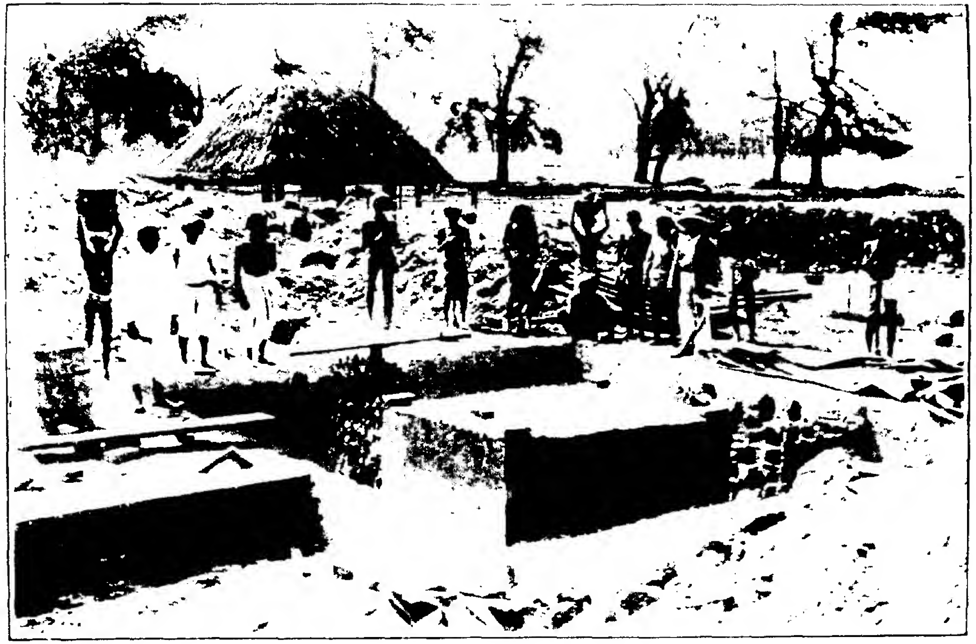


PLATE No XIV

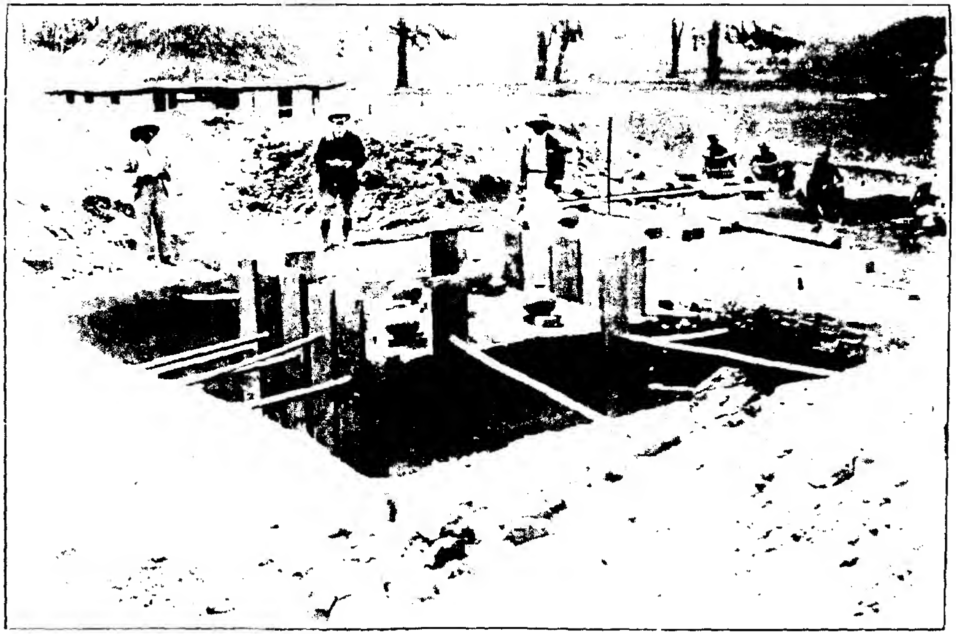


PLATE No XV

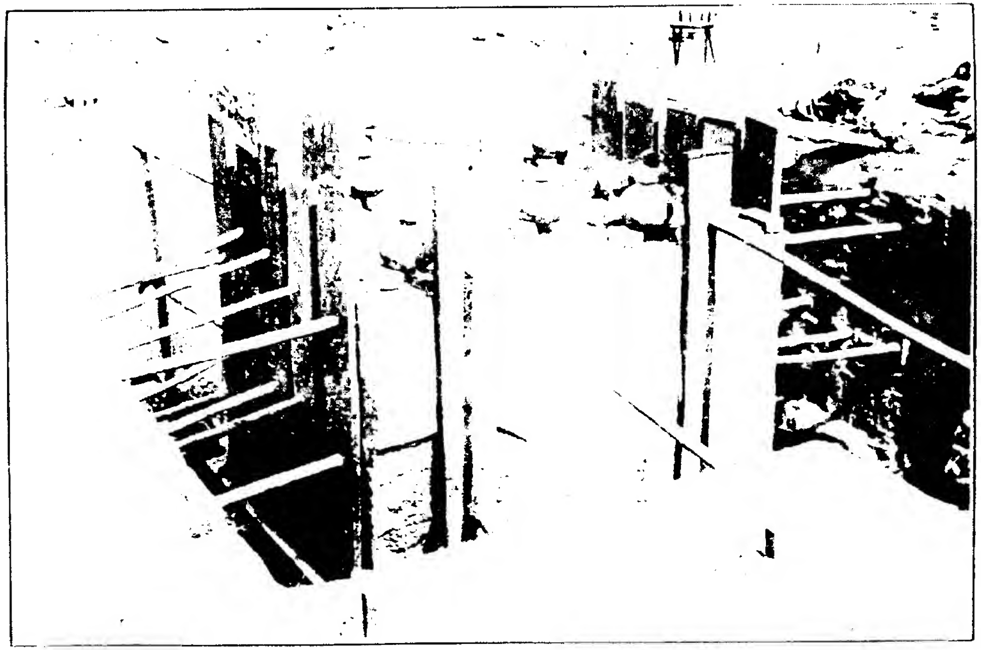


PLATE No. XVI

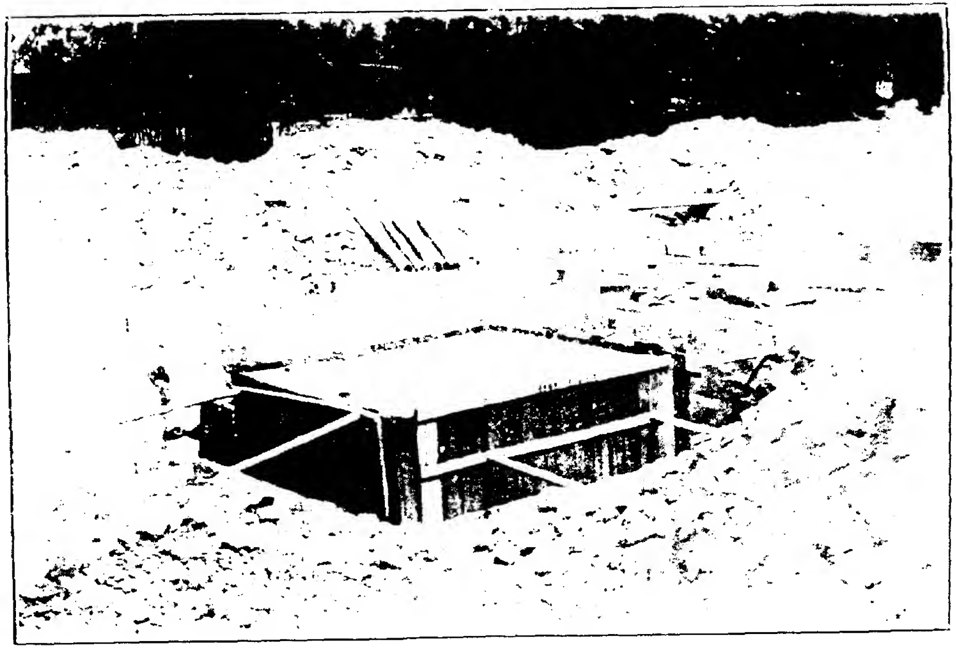
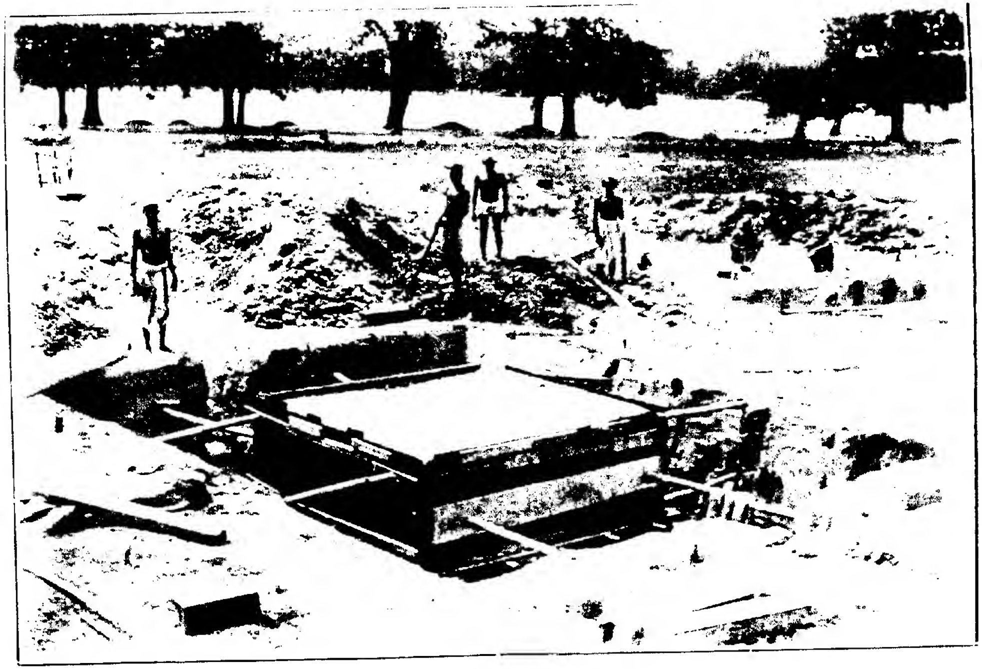


PLATE No XVII



PLAN OF PERFORATED PLATE FOR DRAIN GAUGE.

SCALE ½ INCH = 1 FOOT.

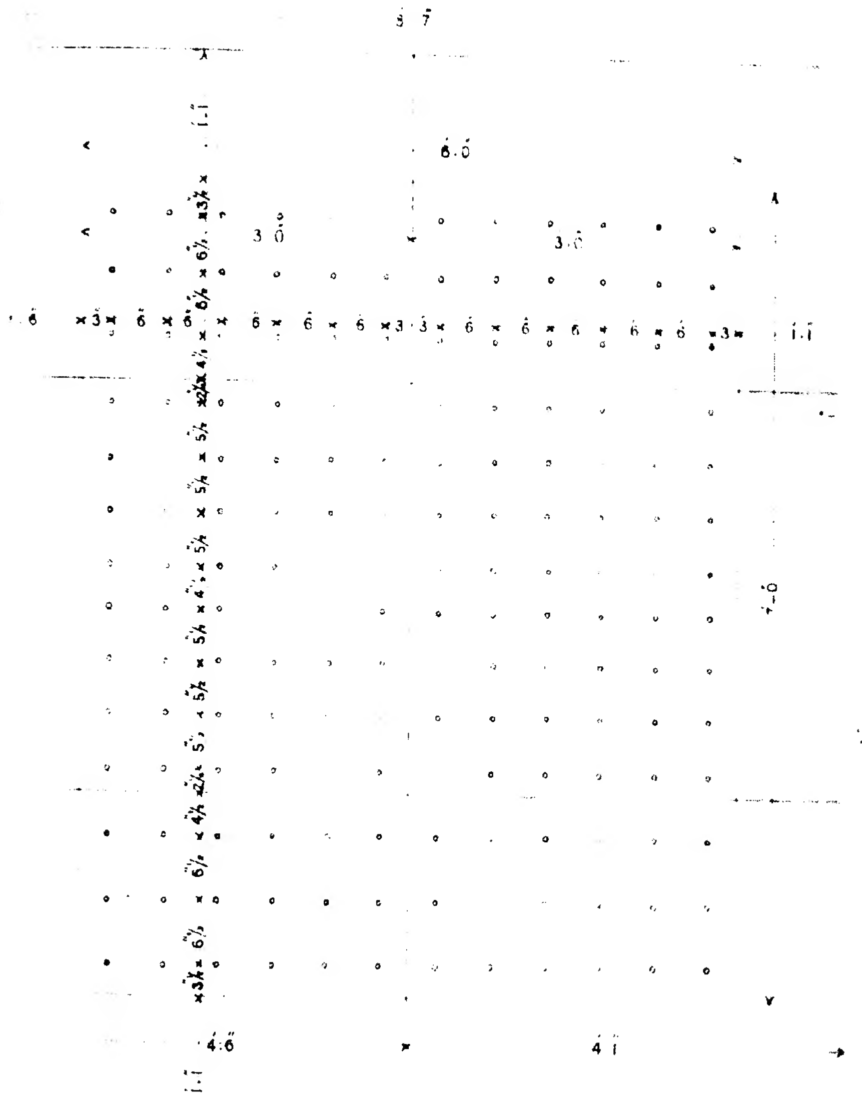


PLATE. XIX.

WALL WITHOUT BUTTRESS SHOWING THE LINE OF THE CENTRE OF PRESSURE FALLING OUTSIDE THE WALL AT A.

SCALE 2 FT. = 1 INCH.

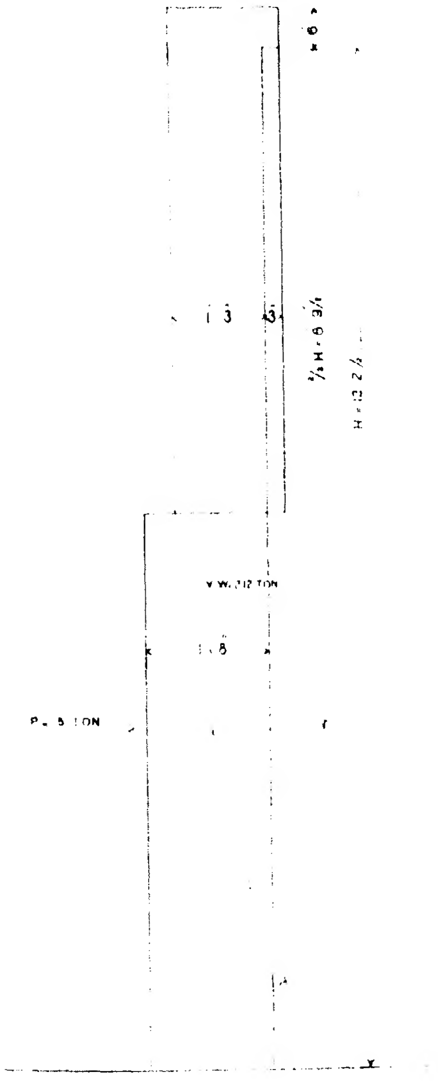
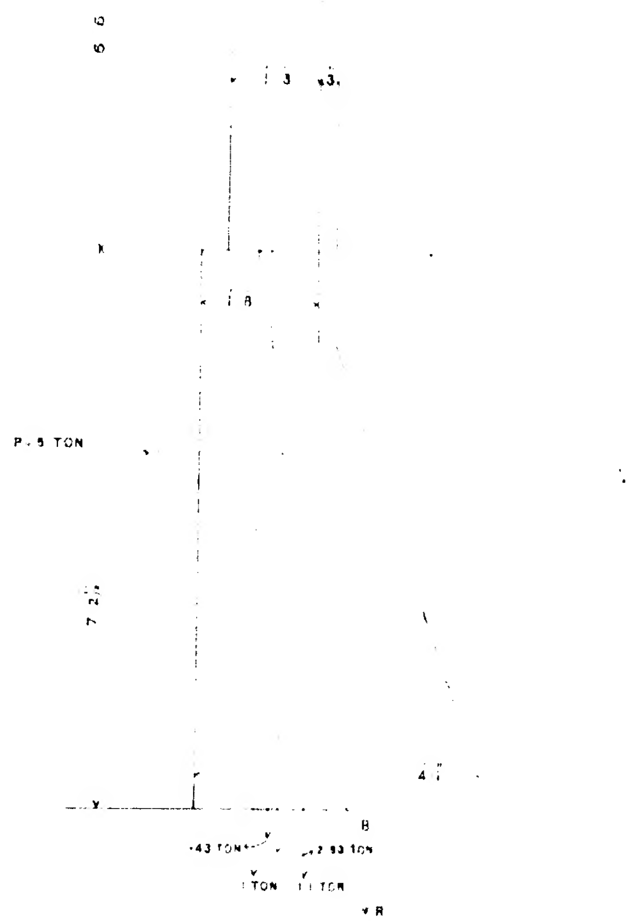


PLATE X.

WALL WITH BUTTRESS SHOWING THE LINE OF THE CENTRE OF PRESSURE FALLING WITHIN THE MIDDLE THIRD OF THE BASE AT A.

SCALE 2 FT.= 1 INCH.



PREFACE.

THE data presented in this Memoir support two important deductions, the one being that during dry weather water moves upwards through the soil from a *limited* depth only; the other, that the rate of loss follows the "compound interest law." The first of these seems to be fully established. The second will require support by means of data obtained in a greater variety of soils, and it is hoped that further evidence under this head may be added during the coming year.

I have received great assistance from Mr. S. C. Kar, M.A., the second assistant in this chemical laboratory, who has carried out patiently the greater part of the elutriation work and computations, and to him this acknowledgment is due.

J. WALTER LEATHER,
Imperial Agricultural Chemist.

THE LOSS OF WATER FROM SOIL DURING DRY WEATHER.

BY

J. WALTER LEATHER, Ph.D., F.I.C., F.C.S.,

Imperial Agricultural Chemist.

INTRODUCTORY

THE general idea regarding the movement of water in the soil during dry periods is that it rises by "capillarity," and since illustrations of this may be given by reference to such phenomena as oil rising up a lamp wick, no difficulty is experienced in obtaining a mental picture of the process. As a matter of fact, it is easy to show that any upward movement of water through the soil must be essentially different from that of the lamp oil. For, in the latter case, fresh oil rises up as fast as the upper portion burns off, and the wick is constantly saturated. Similarly, if one considers a capillary tube containing water; assume that the liquid can rise say x cm. into it; let the upper end be not more than x cm. above the supply of water, and then as fast as water vaporises from the upper end, more will flow upwards and the tube remains permanently full. The soil must be very differently situated, because we know that water does not rise through it "by capillarity" fast enough to replace the vaporised water. There must be some fundamental difference between the two cases. For a similar reason it is, indeed, of little use to experiment in the laboratory with columns of soil, even if these measure as much as two or three feet in height; the difference between this and ordinary field conditions where the subsoil water-level is usually more than 10 ft. and often more than 100 ft. below the surface, is so great as to render deductions from such experiments invalid.

Consider, for example, the experiments quoted by King in "The Soil" (page 174) where columns of soil were placed in water, the water-level being regulated at 1, 2, 3 and 4 ft. from the surface. Water was then found to pass upwards at rates varying from 2·37 pounds to ·9 pounds per sq. ft. per day. If water rose through soils at even the lesser of these rates, no such thing as a drought could occur, for only the heaviest crops require such a quantity of water as this. Indeed, only one writer on this subject, namely, Mr. Lyman Briggs of the U. S. Department of Agriculture, has suggested a rational explanation of the process involved. A quotation may be here suitably given from his paper (Bull. 10, U. S. Dept. of Agriculture, Division of Soils).

"The limit of the capacity of any soil for water is reached when the surface tension holding the water in the capillary spaces is no longer able to overcome the force of gravity acting on the mass. The relative water capacity of two soils, therefore, depends principally upon the number and size of the capillary spaces. By a capillary space as used here is meant not any interstitial space in the soil structure but only that portion of it which is near the point of contact of two soil grains. It is that portion in which the bounding walls are close together, separated only by distances of capillary magnitude and consequently most efficient in retaining water. It is evident that in a soil of fine texture the grains might be so close together as to make all the interstitial space capillary in its nature.

"The one important factor which determines the acquirement and retention of soil moisture is the curvature of the capillary water surfaces. If equal volumes of two soils are placed in contact, and the curvature of the surface is less in the first than in the second, then water will move from the first to the second, increasing the curvature in one and decreasing it in the other until it becomes the same in both soils. If the second soil contains a greater number of capillary spaces than the first, it will contain more water when equilibrium is established. During the adjustment water will have actually moved from a soil containing a low percentage of water to one having a higher percentage. In

no case, however, will water leave a capillary space having a water surface of large curvature to go to a space with a surface of less curvature. It is the form of the surface which determines the movement of the water."

Thus every soil is able to retain by surface tension a maximum amount of water Suppose a series of bodies A, B, C, D (fig. 1) placed one upon another in a vertical column and holding a liquid, say water, in the manner suggested by Briggs. It is clear that such water is held by surface tension; it follows then that this quantity of liquid may be held in a column of indefinite length. If, for example, water is allowed to drop on the topmost solid, it will drain away downwards, leaving behind between the solids precisely that quantity of water which the tension of the liquid surface is capable of suspending. The actual shapes of the water films in the soil are naturally less simple than Briggs's illustration, but the latter supplies nevertheless the simplest representation of the case and forms the basis of a correct knowledge regarding the movements of soil water. Applying these principles to the soil, the following deductions may be made :— (*a*) it is clear that the quantity of water present *after drainage has ceased* depends, *inter alia*, on the nature of the soil and not on the depth at which the subsoil water lies; also that if a coarse soil and a fine soil are in contact, the quantity of water in the coarse soil should be less than in the fine soil.

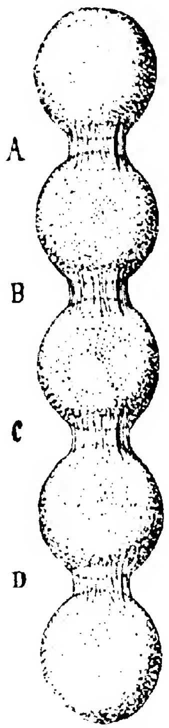


Fig. 1.

(*b*) At the commencement of a dry period, water will assume the gaseous state at the surface of the land; the curvature of the water films in that immediate neighbourhood will be thereby increased and water will commence to flow from neighbouring particles, which in this case are below the surface. The curvature of the water surface

is there increased in a similar manner, and water will flow from the next lower lieing, and so on throughout a series. But this process is not an instantaneous one; time is required for water to move from B to A and until the process is established at B, it will not have begun at C; similarly it will only commence at D *after* it is established at C and so on. This principle must apply to succeeding strata of soil as well as to two succeeding particles, and consequently it is not the case that during dry weather water is moving upward towards the surface from *all* depths down to the underground water-level; on the contrary, we may reasonably expect that there is at any time a certain depth from which water has not yet had time to commence to move upward. It is also to be recognised that so soon as this process is established in any stratum, the amount of water per unit volume must decrease. (*c*) If this deduction is proved to be the case, it must follow that provided the soil is *physically uniform*, during dry weather there will be found, commencing from the surface, increasing quantities of water in succeeding strata. Of this being the actual fact there can be but little doubt, for ordinary field observations illustrate it. It is a fact, however, which cannot be explained by the generally accepted idea of "capillarity." (*d*) A further deduction may also be made, namely, the great probability that the rate at which water leaves the soil during dry periods depends on a law similar to that which governs many processes such as loss of heat from warmer to cooler bodies, or the rate of chemical change, that is, the quantity of water lost per unit of time will depend on the amount of water in the soil. If this were true, it would be a decreasing quantity during any dry period. As I have referred in this introduction to Mr. Briggs's hypothesis, it is perhaps necessary to mention that deductions (*b*), (*c*) and (*d*) are my own. It is hardly necessary to refer to the need there is of a correct understanding of this subject. The movement of water in Indian soils, however important, forms only one of several factors which are involved. We speak for instance of soluble manures being washed away by descending water without any clear idea of the rate at which

such water is moving or the distance to which it will move. Similarly in the case of *usar* land, it is assumed that the salts move upwards and downwards although we have no exact knowledge of the real distances through which the movement takes place.

Experimental.

In order to obtain a correct knowledge of soil moisture conditions, it is essential to make fairly frequent determinations throughout the whole depth of soil which is involved. It is not sufficient for example to record the amount at a particular depth only.

The only accurate means of ascertaining the proportion of water in the soil which we possess is to weigh the fresh earth, dry it and re-weigh it; the loss is assumed to be water. There are other conditions which must be fulfilled, for if the record during a certain period of time is to be at all complete, (*a*) the removal of one set of specimens must not affect the next; (*b*) the whole series must be obtained from such a limited area, that differences in the physical character of the soil may be as slight as possible in the horizontal direction. An ideal case would be realised if the whole of the data could be obtained from one spot: this is impracticable and it merely remains to approach it as nearly as possible. In order to provide these conditions the following procedure was followed:—a plot of land was marked out, and it was decided to restrict the work to fallow land with a loose surface; some records were kept in grass land at first, but it was found impossible to maintain more than one set of data; specimens of the soil were obtained by means of the boring tool subsequently described, to a depth which at first was five feet, and later extended to nine feet from the surface; the relative position of the several borings was such that the one could not affect its neighbour by more than a nominal amount. Regarding this latter point, it will be seen from the description of the boring tool, that after a series of specimens has been removed, an empty

vertical cylinder remains. It is practically necessary to fill this with earth, otherwise the loss of water from this hole might seriously affect the amount of water in the neighbouring soil to an undefined extent; it is also simplest to fill such a hole with dry soil. Now the immediate result of this would be to withdraw moisture from the soil all round. It was assumed that this would take place, and that this dry soil would become equally moist with the surrounding soil, resulting in a lowering of the moisture for a certain distance around its circumference. It was decided that the next boring should not be taken so near that the effect of this partial drying would be as great as ·1 per cent. It was also assumed that the soil contained less than 25 per cent. water, and hence the moisture in the soil surrounding a bore-hole must not be lowered by more than $\frac{1}{250}$th part. It is clear, therefore, that there must be left a volume of soil all round the freshly filled bore hole 250 times its own volume, or since the hole is cylindrical, the radius of the "*affected*" soil will be to that of the bore-hole as the square roots of the respective cross sections; the radius of the bore-hole was 1″ and consequently that of the "affected" earth would be $\sqrt{250} = 15{\cdot}8''$. Since further the next hole would be ultimately surrounded by a similar column of "affected" soil, the distance between any two holes must not be less than $15{\cdot}8 \times 2 = 31{\cdot}6''$. In these experiments 2′ 9″ was allowed. The plot of land was marked by four pegs at the corners, and a chart prepared; any desired point in the area could, therefore, be readily found.

The boring tool. This is illustrated in figs. Nos. 2 and 3 and consists essentially of two parts, namely, the handle and the cylinder. The handle is made in sections so as to admit of deep as well as shallow borings. The cylinders are of iron; they are truly cylindrical *inside* and slightly conical in the lower part outside. It may be mentioned that such a tool could not be used in stony land; but the Indo-Gangetic alluvium consists of fine material only, so that with comparatively slight pressure these cylinders can be forced into the soil, and on withdrawal they remain full of undisturbed soil. Any compression to which the soil is subjected

when the cylinder is forced down is suffered by the soil *outside* the borer. On withdrawal the cylinder is detached from the handle, weighed with the soil in it, and the soil then emptied into a weighed tray in which it is dried. It will be evident that this appliance enables one to obtain the proportion of water in the soil with a minimum of error.

Two sizes of cylinder have been employed; namely, one 3″ long for the upper strata where the variations of water are naturally considerable, and one 6″ long for lower strata. Marks on the shaft indicate when the tool had been driven into approximately the desired depth, but a measurement in the hole was also made, because it not infrequently happens that the specimens taken measure somewhat less or slightly more than the nominal 3″ or 6″ respectively. The record of the exact length of the specimens has enabled me to reduce the weight of water found to terms per unit volume, a figure which is of more service than the percentage.

The nature of the soil.—It has been mentioned that the soil of the alluvium consists of fine material; in fact, excepting for beds of soft concretionary lime-stone, the whole of it passes through a sieve of 2 mm. mesh. The soil at Pusa is unusually fine; in fact, as the elutriations show, nearly the whole of it is less than ·2 mm. in diameter.

Chemically it is characterised by containing about 40 per cent. of chalk. The upper two feet may be described as a loam, the next two feet is much more sandy, and below this it consists of a stiff soil for about 15 feet. The depth to water in a well some 50 yards distant was as follows:—

1906	September, 7th	7′ 5″
	October, 4th	13′ 1″
	October, 15th	14′ 5″
	October, 31st	16′ 0″
	November, 19th ...	17′ 3″
	December, 1st	17′ 8½″
	December, 15th	18′ 1″
1907	January, 3rd	18′ 7″
	January, 15th	18′ 8″

1907	January, 31st	19′ 10″
	February, 16th	20′ 2″
	February, 28th	20′ 4″
	March, 15th	20′ 6″
	April, 1st	20′ 8″
	April, 15th	20′ 10″
	May, 1st	20′ 10″
	May, 18th	21′ 1″
	June, 1st	21′ 8″
	June, 15th	22′ 1″

The great variation in the amount of water at different depths.—The first borings were made early in 1906, and those of 12th February are reproduced in the margin.

Depth.		Water per cent.
0″	3″	16·26
3″	6″	16·05
6″	9″	18·51
9″	10″	21·17
10″	13″	22·91
1′ 3″	1′ 6″	20·79
1′ 6″	1′ 9″	17·89
1′ 9″	2′ 0″	15·78
2′ 0″	2′ 3″	12·50
2′ 3″	2′ 6″	11·80
2′ 6″	2′ 9″	12·67
2′ 9″	3′ 0″	16·19
3′ 0″	3′ 6″	24·11
3′ 6″	4′ 0″	18·12
4′ 0″	4′ 6″	24·19
4′ 6″	5′ 0″	25·37

It is seen that whilst there was 22 per cent. of water at one foot below the surface, there was a sharp decline below this and at 2′ 6″ the soil contained only 11·8 per cent.: an increase in soil moisture followed this until at 3′ 6″ there was 24 per cent.; in the next 6″ there was a decline to 18 per cent. followed by an increase. Such differences could not be ascribed to error of experiment: the three-inch borings weigh between 250 and 275 grms., and as the weight was determined to ·1 grm., no serious error can occur in the weighings. Again, the loss of moisture from the soil between the time it is withdrawn from the hole until it is weighed, does not amount to ·1 grm., and there need be no mechanical loss. Moreover, at the time these specimens were taken there had also been no rain for six weeks. Such differences could only be referred to one cause, namely, difference in the physical state of the soil. This is no new suggestion because the practical agriculturist considers that different classes of soil will hold different amounts of water, though he cannot express the difference more exactly. Mr. Briggs's hypothesis provides an explanation, and he has instanced the effect of physical character in his article in the Year Book of Agriculture, U. S. Department, 1898, page 403. But if this is a correct interpretation, it becomes of all the more importance

to *determine* the exact relationship between physical character of soil and quantity of water held, for if this could be established, it would be possible to determine in the laboratory the amount of water which a soil would hold. The importance of such a method can hardly be overestimated.

At the present time we have only one means of estimating difference of physical character, namely, elutriation, and it was decided to test whether, by this agency, the marked differences in the water capacity of the Pusa soil could be accounted for. This has not been altogether realised; a certain relationship has been established, but it is not of a simple character, and since an examination of the moisture data, apart from the exact physical state of the soil, lead to some interesting results, these will be considered first, and the relationship between physical character and amount of water in a later paragraph.

The data which I propose to consider particularly, relate to the period September 1906 to June 1907, *i.e.*, the dry weather period. The details are set out as follows :—Statement I, percentage of water (dry soil = 100); Statement II, grms. of water per c.c. of undisturbed soil; Statement III, lbs. of water per c. ft. also of undisturbed soil; Statement IV, lbs. of water present in the part of each c. ft examined, that is, if the boring were 3 in. long, this is reckoned as ¼ c. ft.; if 6 in. long, ½ c. ft.; in other words, these figures represent the pounds of water in each section of a vertical column of soil, the cross section of which is 1 sq. ft. The statements III and IV will be the most useful. At first the borings were carried to only 5 ft. deep, but it was soon observed that the dry period was affecting the soil to fully this depth, and since it was most desirable to ascertain the water content to a greater depth than that which was affected by the dry weather, an extra long handle was obtained, and the borings carried to 8 and 9 ft. from the surface. Until the borings were carried below 5 ft., the amount of water was determined in every boring, but when the record was extended to 8 and 9 ft., this became impracticable; the water was then only determined in alternate borings below 12 in. and

the probable amounts in the remaining strata were determined by interpolation. This has been done in statement IV only, and these deduced figures are printed in brackets.

Previous weather conditions.—A description of the rainfall previous to the commencement of the moisture data is desirable.

The monsoon of 1906 was late, and drainage only commenced to flow freely from the six-feet gauge[1] about the middle of July; the major part of the rainfall occurred in August when 24·5 inches fell: September was comparatively dry. The precise details of rainfall are set out in statement V.

STATEMENT V.

Rainfall previous to commencement of observations.

June 1906.		July 1906.		August 1906.		September 1906.	
1st–7th	·30	1st–7th	1·04	1st–7th	7·08	5th	·01
8th–15th		8th–15th	7·76	8th–15th	11·64	8th	·40
16th–22nd	1·11	16th–22nd	·55	16th–22nd	2·98	9th	·72
23rd–30th	4·07	23rd–31st	2·20	23rd–31st	3·11	10th	·37
						12th	·64
						13th	·24
						14th	·08
						15th	·22
						18th	·13

Rainfall during period of observation.

I period.		IV period.		V period.	
26th Sept.	·22"	5th Feby.	·12"	20th Feby.	·08"
28th ,,	·03"	6th ,,	·30"	4th March	·01"
1st Octr.	·32"	7th ,,	·71"	11th ,,	·20"
7th ,,	·16"	13th ,,	·01"	12th ,,	·42"
8th ,,	·08"		1·14	16th ,,	·11"
19th ,,	·01"			17th ,,	·12"
	·82			18th ,,	·78"
				22nd ,,	·11"
				23rd ,,	·02"
					1·85

[1] There are four gauges at Pusa for determining drainage conditions, a description of which is given in Memoir No. 5.—J. W. L.

Rainfall during period of observation—concld.

VI period.		VII period.	
10th April	·36"	19th May	·33"
16th "	·01"	1st June	1·75
18th "	·46"		
29th "	·03"		
30th "	·03"		
	89·		

It is perhaps necessary to mention for those who do not know India, that the Indo-Gangetic alluvium consists entirely of beds of loams, sands, clays, succeeding one another in a more or less well-defined manner. Now, it is a mistake to suppose that because water is found in a certain sandy stratum, no water is draining through the clay below. Clays are not impervious to water; they are merely relatively so. On the other hand, water may accumulate in a sandy stratum much more quickly than it can pass through the underlying clay, and consequently in such a case "underground" water will be found in the sand. Given, however, sufficient time, the excess water will pass through the clay and the sand will not yield water. An upper sand stratum may therefore during periods of excessively wet weather hold the first "underground" water. Owing to the heavy rain during August this occurred in the Pusa soil last year; the underground water was temporarily at four feet from the surface. It was only a temporary state, and drainage ceased from the six-feet gauge from September 6th.

Let us compare also the quantity of water present on July 19th, August 23rd and September 19th. It is clear that the soil was not fully saturated on the former date, that in the middle of August there was excess of water below 3 ft.; thirdly, that by the middle of September the soil contained as nearly as possible as much water as it could hold by surface tension as defined by Briggs's hypothesis. Moreover, there was light rain most days prior to September 19th, and it is probable that at the latter date the soil was just about fully saturated in the surface soil. When the first specimens were taken, the whole

column of soil contained just about as much water as it would hold by surface tension, while it had not had time to dry materially in the surface layer.

The decrease in the quantity of water.—It will be most convenient if we confine our attention to statement III where the pounds of water per c. ft. in the different strata are set out. It will be seen that the dry weather succeeding September rapidly influenced the water in the soil to a depth of 5 ft.: but this influence is not regular. The decrease in the first foot of soil was appreciable in the first month, namely, about 3lbs., but there was no very marked decrease in the second foot until after March; in the third foot, *i.e.*, the more sandy soil, the water fell to one-half in two months: and in the fourth foot the loss was eventually even greater than in the third: below four feet the decrease, though perceptible, was only slight. Later on there was a loss down to a depth of about 7 ft. It is necessary to digress for a moment. The soil examined from depth x at one point in the experimental plot may not be precisely like that taken from the same depth at another point, although only a few feet may separate the two. Consequently differences between individual specimens at this or any particular depth must be substantiated by the quantities found previously and subsequently at the same depth. For example, in May the fourth foot was found to contain only six pounds of water which is much less than the soil of the third or fifth foot, but the correctness of the figure is substantiated, firstly, because it is evident from previous borings that this soil was losing water very rapidly, and, secondly, by the subsequent sample in June. In order then to obtain a correct estimate of the rate of loss, the data should be considered broadly.

Accordingly the quantities of water found in each succeeding foot of soil are set out in statement VI. From this it is evident that the loss from the third foot was most rapid and next to it the fourth foot; from the stiff soil below this, the loss was much less, and in the seventh foot it was nominal. The rapid loss of water from the third and fourth feet is very striking: and for some time I attributed it to belated drainage. But if drainage

had been in progress, the soil below 4 ft. could not at the same time have lost water, whereas it did so; the loss in the fifth foot was only small, but it was definite and the same must be said of the sixth foot. It forms a good illustration of the truth of

STATEMENT VI.

	19th Sept.	20th Oct.	30th Nov.	8th Jany.	15th Feb.	27th Mar.	6th May.	5th June.	25th June.
	lbs. of water.								
0—1 foot	18·07	15·78	14·21	12·15	12·10	14·18	10·83	13·87	10·41
1—2 feet	·96	19·27	17·95	18·17	18·79	19·62	16·39	15·40	15·38
2—3 ..	24·75	18·84	10·68	11·95	12·00	10·51	10·35	9·67	9·03
3—4 ..	25·95	17·51	8·35	13·54	11·27	9·27	6·55	6·63	6·36
4—5 ..	25·65	23·69	21·91	21·07	20·18	19·56	18·40	16·20	16·64
5—6 ..	26·42	25·60	24·50	24·00	23·54	22·45	20·82	19·45	18·99
6—7 ..	26·42	26·00	25·00	25·00	25·30	25·26	24·5	23·10	24·00
TOTAL	169·12	146·69	133·00	125·88	123·18	120·85	107·57	104·32	100·81

Briggs's hypothesis. The sandy stratum contained relatively more water than the loam above, and surface tension occasioned a movement of this excess water into the loam in the second foot at a rate nearly coincident with that at which the second foot

delivered water to the soil in the first foot. This is best illustrated by comparing the rates of loss from these strata.

	Loss.	
	3rd & 4th feet.	2nd foot.
1st period	14·4	14·4 + 1·7
2nd period	7·3	7·3 + 1·3

That is, the second foot lost about one pound more water during the first and second periods than it received.

One conclusion may be definitely drawn from these data, namely, that the deduction made under (b) (page 81) is correct, for it is evident that throughout the nine months of practically dry weather no water moved upwards from a greater depth than 7 ft. ; below this the water was stationary.

The total loss of water.—In order to form an estimate of the total loss of water during the period, the quantities of water present in the upper seven feet must be considered. As no borings lower than 5 ft. were taken until February, it is necessary to assume probable quantities in the sixth and seventh feet up to February, and similarly, as has been fully explained, the amount of water in some of the alternate borings since February has had to be obtained by interpolation. The total water found in each set of borings is placed in the last line of statement No. VI, and it will be seen that, commencing with 169 pounds in the whole seven feet in September, there remained 101 pounds on June 15th ; 68 pounds had therefore evaporated, in addition to the 35 pounds of rain per sq. ft. which fell during the period. The 68 pounds is equivalent to about 40 % of what was in the soil in September at the conclusion of the monsoon, and is rather more than was contained in the uppermost 3 ft. at that time.

The distance to which water moves upwards.—Some writers make a wrong deduction regarding the height to which the water rises during dry periods. For example, King (Experiment Station Record, Vol. XII, page 35) discusses the data of some experiments in which soil, 10 ft. deep, was exposed to drying influences for 10 days, at the conclusion of which time the loss of water

appeared to be felt slightly at 10 ft. from the surface, and he says: "It is certain that a drying of these soils had taken place through a depth of 10 ft. and hence the moisture 10 ft. below the surface of the ground may become available for vegetation purposes at or near the surface." And Hall (Journal of Agricultural Science, Vol I, p. 245) expresses the opinion that nitrates could come from the underground well water at Rothamsted, a distance of some 20 ft. during such brief dry periods as Hertfordshire enjoys, and which are rarely so long as one month. Because water moves *towards* the surface during a dry period is obviously not a proof that it *reaches* the surface. Taking the Pusa data of the past year into consideration, it may be said that the water which was at about 3′ 2″ below the surface in September, reached the surface during the dry weather and evaporated; that the water which in May was in the upper three feet, had come from the fourth and fifth feet: the water which left the seventh foot was only some 3 pounds and merely moved into the sixth foot. It is of course impossible to say from the data we are considering what would happen in other soils. For example, supposing the stratum of sandy soil had been 10 ft. instead of 2 ft. thick, the presumption is that more water would have been lost, partial drying to a greater depth would have been experienced and the water would have moved probably further in the given time. I deduce this merely from the greater rate at which this sandy soil lost water than the loam above it. But it must be rare indeed that water, which at the conclusion of the Indian monsoon is in the *underground water stratum*, reaches the surface during the dry weather period. Similarly, it is equally improbable that the dissolved substances in such water, whether they are the valuable nitrates or the obnoxious *usar* salts, can reach the surface.

The rate at which water was lost.—The third deduction which I made (page 82 (d)) from Briggs's hypothesis is that the quantity of water lost per unit of time will depend on the amount of water in the soil, that is, as the quantity in the soil decreases, so will the rate of loss decline. This is not so simple

a case as loss of heat, or amount of chemical change, both of which follow this law, for it is complicated by the variation in physical nature of the soil and by the ever-increasing depth of soil which becomes involved. Broadly speaking, the data support the hypothesis. The losses from the whole seven feet were as follows :—1st period of 31 days, 22·4 pounds or ·72 lbs. per day; second period of 41 days, 13·7 pounds or ·33 lbs. per day; third period of 40 days, 7·1 pounds or ·18 lbs. per day. The law would be expressed mathematically $\frac{1}{t_n - t_o} \log \frac{Q_o}{Q_n}$ = constant, where t_o is the commencement of the time, t_n the time in days, Q_o the quantity of water present at the commencement and Q_n the quantity present at t_n. But there are other factors which must affect the rate of loss. Temperature and humidity of the atmosphere are two.

Temperature affects both the surface tension and the viscosity. The effect of a rise of temperature on *surface tension* is to lower it, and since this is the cause of water moving upwards in the soil, any decrease in its value would cause a decreased rate of flow towards the surface. This effect would naturally apply to other directions also, but we are only concerned at present with the upward movement. Unfortunately it has not been possible in the past season to maintain a record of soil temperature, and for the purpose of calculation the mean temperature of the air has been assumed to coincide more or less with that of the soil. This has varied from 18° C to 32° C. The surface tension at 18° C = 72·8 dynes per cm., at 32° C = 70·7 dynes. The effect therefore of this change of temperature is only nominal throughout the whole period. The effect of a rise of temperature on the *viscosity* of water is to *decrease* it, with the result that any given force (in this case surface tension) would move a greater quantity of water in unit time. The effect of viscosity is much greater than on surface tension. Taking again the extreme temperature involved, the viscosity at 18° C = ·010 dynes, at 32° C it is ·0077 dynes per sq. cm. Thus, assuming the viscosity of the soil water to be approximately equal to that o

water, about 1/3 more would flow in unit time at the higher than the lower temperature.

The *humidity* of the atmosphere must also be expected to affect the rate of evaporation. If the atmosphere is saturated, it is clear that no evaporation can take place, and similarly, if the humidity is high, the rate of loss must be lower than if the air is dry.

Broadly speaking, these factors would tend to reduce the rate of loss of water from the soil very much during the cold weather, whilst conversely during the hot and dry weather the rate of loss would be much increased.

It follows from these considerations that the velocity of flow, V, would vary directly as the surface tension τ and indirectly as the viscosity, η : it would also vary indirectly as the relative humidity of the atmosphere H.

$$\text{Thus } \frac{V'}{V''} = \frac{\tau'}{\tau''} \times \frac{\eta''}{\eta'} \times \frac{H''}{H'}$$

$$V'' = V' \times \frac{\tau''}{\tau'} \times \frac{\eta'}{\eta''} \times \frac{H'}{H''} \text{ or } V'\,K' \text{ (say).}$$

If the general assumption, that the rate of loss depends on the compound interest law, holds good, then

$$V = \frac{dx}{dt} = K\,(a-x)$$

which on integration yields

$$\log a - \log (a-x) = K\,t$$

or after introducing the correction for temperature and humidity

$$\log (a-x) = \log a - K\,K'\,t,$$

K is a constant obtained for the whole period at mean temperature and humidity (= ·00154). Since the effect of temperature variation on τ was slight and it was known that this formula is not perfect, the surface tension has been assumed to have been constant throughout. In addition to the allowance for the effect of humidity which is included in the formula, I have felt it necessary to assume that while heavy dews occurred, the "day" must be taken at only 12 hours so far as evaporation from the soil is

concerned. A record of the dew was kept throughout the cold weather. The deposit was very regular; it commenced to be heavy on October 14th and continued until the end of February. Every night throughout this period the deposit commenced about 5 or 6 P.M., and evaporation recommenced about 6 A.M. It seems reasonable to assume that evaporation was suspended at night for this period. The result of the computation is set out in the chart, fig. 4.

The quantities of water actually found in the 7 ft. of soil and those calculated are set out in statement VII; the rain which occurred during each period is noted, though it is not included in the water lost.

Statement VII.

	Total. Found lbs.	Total. Calculated lbs.	Loss. Found lbs.	Loss. Calculated lbs.
September 19th, 1906 ...	169·1	...	...	
October 20th, 1906	146·7	(4·2 lbs. rain per sq. ft.) 155·9	22·4	13·2
November 30th, 1906	133·0	(no rain) 145·4	13·7	10·5
January 8th, 1907 ...	125·9	(no rain) 137·6	7·1	7·8
February 15th, 1907	123·2	(6·0 lb. rain per sq. ft.) 135·1	2·7	2·5
March 27th, 1907	120·8	(9·6 lbs. of rain) 128·6	2·4	6·5
May 6th, 1907 ...	104·3	(4·6 lbs. of rain) 103·8	3·3	4·5
June 15th, 1907	100·8	(no rain) 99·1	2·5	4·7

An examination of the chart and of this statement shows that the calculated *rate of loss* was in considerable defect during the first period (September 9th to October 20th): it then agrees closely with the actual until the hot weather March to May when it was greater than the actual, after which agreement again occurs.

The effect of rainfall. The effect of such rainfall as occurred is best traced in statement IV. Although borings were not made immediately subsequent to rain, it is clear that in no case was the moisture increased beyond about 1′ 6″ from the surface. The rainfall of February 5th, 6th and 7th, 1·13″, seems to have

affected the first foot; that of March, 1·77", appears to have increased the moisture in the second foot; that of June 1st, 1·75", affected only the first foot, or at least this is all the evidence of increased moisture remaining on the dates of sampling.

Relation between physical state and amount of water.—The term "Physical state" is often employed in regard to soils as though it were an entity. That it is a mistake to use it in this sense will be readily admitted. The physical properties of soils are, doubtless, as numerous as their chemical properties. It is probable that the collective term is employed because of our general ignorance of the precise properties which occasion or control certain effects. The quantity of water held by soils is one of these effects.

In an earlier paragraph I have sufficiently explained my reasons for considering Mr. Briggs's hypothesis a reliable one. According to it, the water in the soil should distribute itself by surface tension among the particles in such a manner that when the soil is losing water neither by drainage nor evaporation, the curvature of the small surfaces will be equal. Under such circumstances, the amount of water held between any two large particles will be greater than between any two small ones, but the quantity of water held by a unit volume of small particles will be greater than by the unit volume of large particles. In short, a sandy soil should contain a less amount of water than a finer soil. Such is the hypothesis. I have also pointed out that the earliest borings in the Pusa soil showed considerable differences in the amounts of water contained in the 100 parts of soil (by weight), the differences being indeed more marked than an inspection of the soil would have led one to anticipate. Although it is simple to refer such differences to difference of "physical properties", such a conclusion is of no practical utility. If the effect is due to that cause, it becomes essential to the correct solution of the problem that the real nature of the particular "physical properties" shall be established.

One suggestion very naturally occurred, namely, to compare the total surface possessed by the soil particles with the water

present. This physical property, although difficult to estimate correctly, is at least fairly well defined.

Mr. Briggs's hypothesis does not demand that the quantity of water present shall correspond to the *total surface*; it would demand a *relatively* smaller amount of water per unit of surface in coarse than in fine soils. But since any one soil does not consist simply of particles of one size, there being merely a larger proportion of coarse, or of fine particles in its volume, one cannot expect that this feature will be in any case well marked.

On noticing the varying proportions of water in the Pusa soil, I decided to employ the only means we have for the determination of the total surface of the soil particles, namely, elutriation, and make the indicated comparison. The result of one of the first experiments was extremely encouraging and is shown in the marginal statement VIII. As already seen, the experiment supported the hypothesis, and a close relationship between water and total surface was demonstrated. This work was, therefore, prosecuted. Other features also came into evidence and will be referred to subsequently.

STATEMENT VIII.

Depth.	Water. %	Ratio water : surface.
9" – 1' 0"	20·91	·073
1' 0" – 1' 3"	23·00	·074
1' 3" – 1' 6"	19·84	·071
1' 6" – 1' 9"	16·36	·068
1' 9" – 2' 0"	12·57	·081
2' 0" – 2' 3"	9·87	·086

Method for the determination of the total surface.—Only one method for the approximate estimation of the total surface is available, namely, the separation of the several principal grades of particles by sedimentation or elutriation, and the ascertainment of their magnitude. Of elutriation methods I have found simple sedimentation in beakers very good. Without criticising other methods specifically, it may be said that for the grading of the *finest* portions, I have found the beaker method preferable to any "running water" method.

The process which I have employed is extremely simple. A weighed portion, usually 10 grms., of the air-dry soil is heated with water and then stirred up in cold water, 10 cm. deep, in a

beaker; subsidence is then allowed for a definite period, the muddy water decanted and the process repeated so long as is necessary. The mean diameter possessed by the particles is then obtained by a microscopical estimate, and the total surface deduced from this on the assumption that the particles are spheres, together with the ultimate dry weight of the sediment. The periods of sedimentation employed have been 24 hours, 30 minutes, 10 minutes, 75 seconds. In some of the work a 6 hours' sedimentation was used and will be specially noticed. It was without material influence on the result.

There are one or two points that are here deserving of special remark.

(*a*) The *uniformity* of the sediments is naturally most important, and in this respect I have found the method more reliable than might perhaps be anticipated. In Figs. Nos. 5 to 8 are reproduced the photomicrographs of a series of sediments together with the magnification, and it is apparent that from such sediments it is quite possible to estimate the mean diameters. They have been all through the work most reliable. The only sediment which, microscopically, has proved irregular, is that for 24 hours. It is commonly called "clay", and consists for the most part of ill-defined material together with a small quantity of particles of irregular size. The Pusa soil contains very little of this, so much as 3 per cent. being very unusual.

(*b*) The sub-division of the two hours' sediment into two portions, one of 6 hours' sedimentation and the other of two hours, was tried in a number of specimens, but the effect of making this differentiation was only slight. For example:—

STATEMENT IX.

Depth.	With 6 hours' sedimentation followed by 2 hours' sedimentation $R \times 10^6$.	With only 2 hours' sedimentation. $R \times 10^6$.
2' 9"–3' 0"		7·6
3' 0"–3' 6" ...	8·0	...
3' 6"–4' 0" ...		6·8

Depth.	With 6 hours' sedimentation followed by 2 hours' sedimentation. $R \times 10^6$.	With only 2 hours' sedimentation. $R \times 10^6$.
4′ 6″–5′ 0″	9·3	
5′ 6″–6′ 0″		8·7
6′ 6″–7′ 0″	6·6	
7′ 6″–8′ 0″		7·6
8′ 6″–9′ 0″	7·6	

(*c*) The effect of employing dilute ammonia instead of water for the sedimentations has been recommended by some; it was only used in a few tests, but this also yielded results which agreed well with what had been obtained by means of pure water. The figures are sub-joined.

	(1)	(2)	(3)	(4)
		Sq. cm. per 1 c. c. of soil.		
With water only ...	1823	1578	1947	3876
With dilute ammonia ...	2128	1787	2113	3356

(*d*) It is desirable to decide in some methodical way, how often to decant the suspended sediment. It is commonly recommended that sedimentation should be repeated until there remains no suspended matter at the conclusion of the stated period. In my experience this point is either never reached or it is reached only after the employment of altogether excessive amounts of water. In attempting to arrive at a really clear supernatant liquid I have frequently had to use so much water that the quantity of soil dissolved would be greater than the suspended matter. Indeed, there is no object in carrying out the separation of the sediments in this way. Suppose, for example, elutriation is stopped for any particular sediment when only 9/10 has been separated, and the remaining 1/10 is left to be separated with the next coarser material, what will be the ultimate effect on the estimate of surface? Here is a comparison :-

(i) $R \times 10^6 = 7·0$; if 1/10 of each sediment had been left as suggested, the ratio becomes 7·5.

(ii) $R \times 10^5 = 11 \cdot 0$: if 1/10 of each sediment had been left over, it would have become 11·8.

Such differences, though appreciable, are not so great as the other errors of experiment which are necessarily involved. At the same time there is no necessity to leave even so large a proportion of any sediment as 1/10. If the series of decantations are poured into separate vessels, it is seen that the quantity of sediment in each succeeding decantation diminishes rapidly, and in fact it will rarely or never be found that the amount of sediment in the tenth decantation forms a material proportion of the whole. The following procedure has, therefore, been adopted in this laboratory; the first three decantations are poured into one vessel, and the succeeding three into another: it is quite easy to judge by the eye whether the latter is much less than the former or not: if it is large, then decantation is continued for another three times. It often happens that the amount of sediment obtained in the second three decantations is so small that the whole of that particular grade may be considered to have been satisfactorily separated, and further sedimentation becomes unnecessary. As an example of the reliability of this mode of procedure, the following may be quoted:—

By decanting until the water was clear.	By decanting 6 to 9 times according as considered desirable.
Sq. cm.	Sq. cm.
3097	3138

After completing the elutriations the surface possessed by the various sediments was calculated as sq. cms. and from this was deduced the surface per 1 c. c. of soil *in situ*. This is called S. The ratio of water (1 c. c. = 1 grm.) per 1 c. c. of soil to S was then obtained. It is called R. As it is a small fraction, it is convenient to multiply it by 10^5.

The whole of the samples from September 1906 to May 1907, besides two series in March and April 1906, 157 in the aggregate, have been thus tested and the details are set out in the Statements Nos. X to XIX. For the purpose of more easy reference the values of $R \times 10^5$ are collected in Statement No. XX which

STATEMENT No. XX.

Values of $R \times 10^5$.

Depth.	1906. 19th Mar.	2nd April.	19th July.	19th Sept.	20th Oct.	30th Nov.	1907. 8th Jany.	15th Feb.	27th Mar.	6th May.
0" – 1' 0"	11·49 8·64 7·75 7·73	8·91 8·95 6·54 7·24	10·90 10·34 8·54 8·65	15·86 11·75 9·13 8·60	10·6 9·28 7·21 7·26	10·4 8·9 7·7 6·9	8·7 7·4 8·1 8·4	9·8 8·8 7·5 7·8	8·6 8·4 6·8 5·8	6·1 6·9 6·1 5·6
1' 0" – 2' 0"	7·06 7·38 7·95 8·94	7·33 7·14 6·77 8·16	8·05 8·02 8·73 12·60	8·56 8·99 9·76 10·90	7·66 7·99 8·79 10·3	6·5 7·0 8·0 9·5	7·0 7·7 7·7 8·5	5·6 7·2	5·6 7·4	5·9 7·0
2' 0" – 3' 0"	9·66 10·10 10·50 10·25	8·04 10·17 11·16 10·96	16·89 19·26 22·22 19·84	17·39 18·19 18·17 22·16	13·7 15·2 16·9 20·4	10·6 11·2 11·0 11·9	8·9 10·2 11·1	9·5 10·8	11·6 10·3	7·9 7·6
3' 0" – 4' 0"	11·08 10·12	11·71 10·81	20·14 10·77	39·84 14·41	17·3 17·2	13·9 13·5	12·4 11·6	15·5	11·3 8·3	7·9 6·9
4' 0" – 5' 0"	10·43 11·77	9·67 11·58	11·42 14·47	11·65 17·90	11·3 13·6	9·7 12·8	9·8 11·6	8·7 10·1	10·0	9·3
5' 0" – 6' 0"								9·3	7·2	8·7
6' 0" – 7' 0"								7·1	7·9	6·6
7' 0" – 8' 0"								7·7	7·1	7·5
8' 0" – 9' 0"									7·9	7·6

exhibits the nett results very well. In the first place, the ratio for the borings of September 19th should be compared with the water per c.ft. (Statement III). From the latter it is seen that the amount of water rose from about 16lbs. per c.ft. in the second three inches to about 25lbs. at 2′ 6″, after which the variations were nominal. This was at a period immediately after drainage had ceased. It was reasonable to anticipate that the sandy stratum would have a relative excess of water; in other words, R should be higher in the sandy stratum at that time than either in the loam above or in the clay below. Reference to Statement No. XX shows that in fact this was the case. R is very fairly constant until the sandy stratum is reached; in this it is high, being exceptionally high at 3′ 0″–3′ 6″ below which it rapidly declines again. So far then the actual state agreed with anticipation. In the next place, it was to be expected that there would follow a redistribution of water from the sandy stratum to the loam and the clay so that R would become uniform. This also occurred, although the change was more gradual than I expected, and the great difference in this ratio of September took about ten weeks—until the end of November—to disappear. The alteration of these ratios coincided with the losses of water by evaporation. It may be suggested that the upper loam contained its maximum amount of water, and that if water was brought into it from below, a like quantity must pass upwards away from it; that is, R could not be greater in this soil, *i.e.*, the upper loam, than about 9×10^{-5}. It is also to be noted that R could be more than three times as great in the sandy soil as it ever was found to be in the loam or the clay, excepting when drainage was in progress in the latter (*vide* 5′ 0″ on September 19th; R = 17·9 indicates that drainage perhaps had not quite ceased at this depth). Another point to be noted is that when this ratio was abnormally high, the rate of evaporation was likewise higher than was expected from the mode of calculation which I have adopted in the former part of this Memoir.

Passing in the second place to a review of R during the later periods, it will be seen that it decreased in all strata, though the

amount of change in its value varied a good deal. In the first foot the change was gradual throughout the season; fluctuations occurred, but these could be accounted for by individual rainfalls. In the second foot the change was gradual until February after which the ratio became approximately constant. In the third foot the fall in the value of R was very rapid during the first two months, after which it decreased gradually. To the next six inches of soil, the most sandy of all, a similar remark applies. The following six inches of soil varied a good deal among the borings. In the fifth foot the value of R fell regularly throughout the season.

Some of the data of water per c. ft. and the ratio, R, may be collected for comparison and the season divided into two periods, namely, September to November and November to May.

	September to November.		November to May.	
	$R \times 10^4$.	Water per c. ft.	$R \times 10^4$.	Water per c. ft.
0"–1' 0"	11·3 – 8·5	18·9 – 14·2	8·5 – 6·1	14·2 – 10·8
1' 0"–1' 9"	9·1 – 7·2	20·7 – 18·6	7·2 – 5·9	18·6 – 18·1
2' 0"–3' 0"	19·0 – 11·2	24·7 – 10·7	11·2 – 7·6	10·7 – 10·4
4' 0"–5' 0"	14·8 – 11·2	25·6 – 21·9	11·2 – 9·3	21·9 – 18·1

An inspection of these figures shows that the change in the value of R followed generally that of the water; in the first foot and the following nine inches and in the fifth foot this change was indeed as nearly proportional as could be expected; in the sandy soil of the third foot the relationship was imperfect. Here again, then, irregularity is apparent in the sandy subsoil.

The general value of elutriation. The question may naturally be considered whether elutriation may be employed to determine the maximum quantity of water a soil will hold and the probable rate at which it will lose water in dry weather. Only approximate deductions can be drawn from the data at hand, which may be thus stated:—

(*a*) The sandy stratum possessed a surface of 1,000 to 2,000 sq. cm. per c.c. of soil. This is the soil which lost its water so rapidly.

(*b*) The loam from 1′ 9″ to 2′ 9″ possessed a surface of 3,000 to 4,000 sq. cm. per 1 c.c., and it retained its water extremely well.

(*c*) The same remark applies to the clay below the sand, though its surface was equal to 3,000 up to 6,000 sq. cm. per 1 c.c. Until, however, a greater variety of soils have been tested, it will be impossible to say whether elutriation will yield with them corresponding results. Obviously, however, if by elutriation the water holding capacity of soils can be determined, it is clear that the method would have a great agricultural value.

General conclusions.—The general conclusions which may be drawn from the data dealt with in this memoir may be summarised as follows:—

(*a*) During a dry period water moves upwards towards the surface from a *limited* depth only; this limited depth increases with the period. Below this depth the water is stationary, or possibly is still draining downwards. In the Pusa soil this depth was eventually about 7 ft. If the sandy stratum had not been present, it would probably have been much less.

(*b*) In the Pusa soil the maximum distance that water moved upwards was somewhat more than three feet during the whole period, and this distance was considerably less for the water which was originally in the lower strata.

(*c*) Water is lost from the soil at a rate dependent on the amount of water present, *i.e.*, it follows the "compound interest law." It is influenced by temperature because of the marked change of viscosity; the change in the surface tension is only slight for such ranges of temperature as occur. It varies inversely with the humidity.

(*d*) The rate of loss is much greater immediately after rain than subsequently.

(*e*) The effect of such cold weather and hot weather showers as were experienced during the period under review (maximum 1·75″) increased the water throughout the first foot, but did not extend below the second foot of soil.

(*f*) All soil such as is included in the strata examined will contain about 25lbs. of water per c. ft. at the conclusion of the monsoon, provided this is normal.

(*g*) A soil possessing not more than 2,000 sq. cm. of surface per 1 c.c. of soil *in situ* will lose water very much more rapidly than one possessing 4,000 to 6,000 sq. cm. of surface.

(*h*) There is one case which perhaps specially requires remark, namely, the rate of loss from a very sandy soil. It has been shown how rapid this was from the sandy subsoil at Pusa. But if a sandy soil is exposed *at the surface*, the circumstances are altered in one particular. At first the loss would be rapid, but this class of soil dries so effectively at the surface that several inches will become air-dry. The soil in which surface tension is able to act is therefore protected by a layer of dry material, through which water passes, not in the liquid form by surface tension, but as gas by diffusion. This process is extremely slow. In a recent paper by Mr. E. Buckingham (Bull. 38, U. S. Dept. of Agric., Bureau of Soils) he describes experiments in which the loss by gaseous diffusion through only 2″ of dry sand aggregated only 1·4 to 4·3 inches per 12 months. Consequently after the surface two or three inches of a sandy soil have become *really* dry, the rate of loss would be largely controlled by this factor and would become less. This explains why very sandy soils, although quite dry at the surface, are always found to be perceptibly damp a few inches below.

(*i*) The water-retaining power of a soil after drainage has ceased, is closely related to the total surface possessed by the solid particles, and it is probable that from a determination of the latter, the water-holding capacity of soils may be ascertained.

(*j*) These conclusions have a value beyond the mere knowledge of the rate of movement of water. They show that soluble substances, valuable plant-foods as also deleterious alkali salts, cannot move during dry weather more than a very limited distance. It is impossible, for example, for salts which are present in well-water to reach the surface unless that subsoil water is only at a very moderate depth, such as 5 or 7 ft. This not merely limits

assumptions on the subject of alkali, but also simplifies work in relation to the possible distribution of plant food.

(*k*) These deductions are in accordance with what is known in practice. They explain why a crop will wither when the soil below the root range still contains abundance of water; the latter simply cannot move upward fast enough to meet the plant's requirements. Also, why a crop will mature in some soils with a very limited assistance from rain or irrigation, whereas in other soils the crop will require this aid constantly throughout the period of growth. Broadly speaking, crops depend simply on the water which is present in the stratum in which they are developing and receive only a very limited assistance from below. It is also clear why it is that only the uppermost soil dries to any marked extent.

(*l*) The term "capillary" should be discontinued in relation to soil moisture conditions. It is true that surface tension is the cause of liquids rising in capillary tubes, also the cause of the retention of water in soils; but the term capillary should be restricted to the case of a liquid completely filling a narrow space. In the upper soil, *i.e.*, the aerated soil in which our crops develop, this condition does not obtain and hence the impropriety of the term "capillary."

Depth.	Nov. 30th H_2O%	1907. Jan. 8th H_2O%	Feb. 15th H_2O%	March 27th H_2O%	May 6th H_2O%	June 5th H_2O%	June 15th H_2O%
	No. 13	No. 14	No. 30	No. 35	No. 27	No. 31	No. 36
0"–3"	15·85	12·77	14·48	12·48	8·81	17·13	8·58
3"–6"	16·67	12·49	15·38	13·65	11.04	13·82	13·12
6"–9"	16·35	13·96	15·35	15·42	12·23	14·72	13·49
9"–1'0"	19·77	19·76	15·95	20·35	18·10	19·06	12·70
1'0"–1'3"	22·62	23·25	...	...	...	...	......
1'3"–1'6"	22·75	23·09	22·83	23·29	21·01	20·43	19·84
1'6"–1'9"	21·42	21·89	...	...	...	...	...
1'9"–2'0"	19·36	20·68	22·24	17·22	13·98	13·91	13·80
2'0"–2'3"	14·39	17·11	...	...	...	...	......
2'3"–2'6"	11·88	12·94	12·05	17·29	11·70	11·84	10·02
2'6"–2'9"	12·22	12·58	...	...	...	...	...
2'9"–3'0"	15·44	16·54	15·99	14·79	13·24	11·02	11·54
3'0"–3'6"	24·61	20·38	15·73	11·42	6·23	6·19	6·74
3'6"–4'0"	19·81	12·69	..	.	9·85	10·75	9·13
4'0"–4'6"	24·39	22·69	22·66	...	...		....
4'6"–5'0"	25·46	23·20	22·49	22·48	20·58	18·22	17·67
5'6"–6'0"	.....	......	26·00	25·13	24·09	21·81	26·50
6'6"–7'0"	.	...	28·02	26·75	27·14	24·81	26·50
7'6"–8'0"	....	....	28·30	24·21	28·08	26·14	26·59
8'6"–9'0"	.....	.....	.	29·13	28·77	28·57	28·53

STATEMENT No. 11.

Grams of Water per c.c. of soil.

Depth.	1906. 19th Mar. No. 4.	2nd April No. 5.	19th July No. 40.	22nd Aug. No. 10.	9th Sept. No. 15.	20th Oct. No. 16.	30th Nov. No. 13.	1907. 8th Jany. No. 11.	15th Feb. No. 30.	27th Mar. No. 35.	6th May No. 27.	5th June No. 31.	15th June No. 36.
0"–3"	·2122	·1528	·2731	·3631	·3256	·2246	·210	·1702	·1974	·1657	·1211	·246	·1223
3"–6"	·1942	·2129	·2900	·3528	·2874	·2181	·245	·1761	·2188	·1741	·1599	·198	·1741
6"–9"	·2052	·2097	·2911	·3366	·2926	·2686	·192	·1786	·2065	·2162	·1670	·188	·1955
9"–1'0"	·2583	·2822	·2947	·3366	·3100	·3003	·264	·2531	·1651	·3061	·2495	·257	·1748
1'0"–1'3"	·3269	·2884	·3079	·3217	·3184	·3262	·304	·3049					
1'3"–1'6" ...	·2841	·2446	·3307	·3683	·3249	·2757	·305	·2893	·2965	·3450	·2000	·268	·2680
1'6"–1'9" ...	·2388	·2026	·3599	·3948	·3508	·3262	·383	·2932					
1'9"–2'0"	·1780	·1631	·2911	·4091	·3495	·3068	·258	·2757	·3139	·2233	·1812	·183	·1819
2'0"–2'3"	·1871	·1282	·2751	·3933	·3618	·2647	·181	·2233					
2'3"–2'6" ...	·2013	·1184	·2777	·4576	·4091	·2589	·149	·1642	·1540	·1612	·1528	·154	·1288
2'6"–2'9" ...	·2304	·1353	·3715	·4568	·4149	·3094	·157	·1580					
2'9"–3'0"	·1976	·1778	·4065	·5351	·4013	·3741	·198	·2214	·1987	·1603	·1773	·147	·1534
3'0"–3'6"	·1116	·2666	·3127	·3461	·3988	·2852	·324	·2674	·2010	·1369	·0899	·079	·0851
3'6"–4'0" ...	·2307	·1874	·3522	·4506	·4325	·2758	·264	·1667	...		·1292	·140	·1188
4'0"–4'6" ...	·3331	·3332	·3862	·4400	·3985	·3678	·350	·3395	·3257				
4'6"–5'0" ...	·3318	·3190	·4073	·4976	·4234	·3911	·352	·3355	·3208	·3134	·2901	·269	·2665
5'0"–5'6"													
5'6"–6'0" ...				...					·3858	·3752	·3480	·329	·3179
6'0"–6'6"					...								
6'6"–7'0" ...					...		...		·4087	·4147	·4079	·384	·4066
7'0"–7'6" ...													
7'6"–8'0" ...			...						·4107	·3593	·4212	·405	·4060
8'0"–8'6"													
8'6"–9'0"			...							·3739	·4325	·430	·4299

STATEMENT No. III.

Pounds of Water per c. ft. of soil.

Depth.	1906. 19th Mar. No. 4.	2nd April No. 5.	19th July No. 40.	22nd Aug. No. 10.	19th Sept. No. 15.	20th Oct. No. 16.	30th Nov. No. 13.	1907. 8th Jany. No. 14.	15th Feb. No. 30.	27th Mar. No. 35.	6th May No. 27.	5th June No. 31.	15th June No. 36.
0″–3″	13·25	9·54	17·05	22·67	20·33	14·02	13·11	10·63	12·32	10·34	7·56	15·36	7·64
3″–6″	12·12	13·20	18·11	22·62	17·94	13·62	15·30	11·90	13·66	10·87	9·98	12·37	10·87
6″–9″	12·81	13·09	18·17	21·01	18·27	16·77	11·98	11·15	12·89	13·50	10·43	11·72	12·20
9″–1′0″	16·13	17·62	18·40	21·01	19·35	18·75	10·48	15·80	10·31	19·11	15·35	16·04	10·91
1′0″–1′3″	20·41	18·00	19·22	20·13	19·88	20·37	18·98	19·04					
1′3″–1′6″	17·74	15·27	20·65	22·90	20·28	17·21	19·04	18·06	18·51	21·54	18·10	16·73	16·73
1′6″–1′9″	14·91	12·65	22·47	24·65	21·90	20·37	17·67	18·30					
1′9″–2′0″	11·11	10·18	18·17	25·54	21·82	19·15	16·11	17·21	19·60	13·94	11·32	11·43	11·35
2′0″–2′3″	11·68	8·06	17·17	24·56	22·58	16·53	11·30	13·94					
2′3″–2′6″	12·57	7·39	17·34	28·57	25·54	16·16	9·30	10·25	9·62	10·06	9·54	9·62	8·04
2′6″–2′9″	14·38	8·45	23·19	28·52	25·90	19·32	9·80	9·86					
2′9″–3′0″	12·34	11·10	25·38	33·68	25·05	23·36	12·36	13·82	12·41	10·01	11·07	9·17	9·58
3′0″–3′6″	6·97	16·64	19·52	21·61	24·90	17·81	20·23	16·69	12·55	8·55	5·05	4·52	5·31
3′6″–4′0″	14·40	11·70	21·90	28·13	27·00	17·22	16·48	10·41			8·06	8·75	7·42
4′0″–4′6″	20·80	20·80	24·11	27·47	24·88	22·96	21·85	21·20	20·33				
4′6″–5′0″	20·72	19·92	25·43	31·06	26·43	24·42	21·98	20·95	20·03	19·56	18·11	16·21	16·64
5′0″–5′6″													
5′6″–6′0″									24·71	23·42	21·73	20·54	19·85
6′0″–6′6″													
6′6″–7′0″									25·51	25·89	25·47	23·97	25·38
7′0″–7′6″													
7′6″–8′0″									25·64	22·43	26·29	25·30	25·34
8′0″–8′6″													
8′6″–9′0″										23·34	27·00	26·82	26·84

STATEMENT No. IV.

Pounds of Water actually present in the soil.

Depth.	1906 19th Mar. No. 1.	2nd April No. 5.	19th July No. 10.	2nd Aug. No. 10.	12th Sept. No. 15.	20th Oct. No. 16.	30th Nov. No. 13.	1907 8th Jany. No. 14.	15th Feb. No. 30.	27th Mar. No. 35.	5th May No. 27.	5th June No. 31.	15th June No. 36.
0"–3" ...	3·31	2·38	4·26	5·67	5·08	3·50	3·28	2·66	3·08	2·58	1·89	3·84	1·91
3"–6"	3·03	3·32	4·53	5·50	4·48	3·40	3·82	2·75	3·22	3·40	2·49	3·07	2·72
6"–9" ...	3·20	3·27	4·54	5·25	4·57	4·19	2·99	2·79	3·22	3·40	2·61	2·93	3·05
9"–1'0" ...	4·03	4·40	4·60	5·25	4·84	4·60	4·12	3·95	2·58	4·80	3·84	4·01	2·73
1'0"–1'3" ...	5·10	4·50	4·80	5·03	4·97	5·00	4·74	4·76	(4·63)	(5·38)	(4·52)	(4·18)	(4·18)
1'3"–1'6"	4·43	3·82	5·16	5·75	5·07	4·30	4·76	4·51	4·63	5·38	4·52	4·18	4·18
1'6"–1'9"	3·73	3·16	5·62	6·16	5·47	5·09	4·42	4·60	(4·63)	(5·38)	(4·52)	(4·18)	(4·18)
1'9"–2'0"	2·78	2·54	4·54	6·39	5·45	4·79	4·03	4·30	4·90	3·48	2·83	2·86	2·84
2'0"–2'3" ...	2·92	2·00	4·29	6·14	5·64	4·13	2·82	3·48	(3·65)	(3·00)	(2·60)	(2·63)	(2·43)
2'3"–2'6" ...	3·14	1·85	4·33	7·14	6·38	4·84	2·32	2·56	2·40	2·51	2·38	2·40	2·01
2'6"–2'9"	3·59	2·11	5·80	7·13	6·47	4·83	2·45	2·46	(2·85)	(2·50)	(2·60)	(2·35)	(2·20)
2'9"–3'0"	3·09	2·77	6·34	8·42	6·26	5·84	3·09	3·45	3·10	2·50	2·77	2·29	2·39
3'0"–3'6"	3·48	8·32	9·76	10·80	12·45	8·50	10·11	8·34	6·27	4·27	2·52	2·26	2·65
3'6"–4'0" ...	7·20	5·85	10·99	14·06	13·50	8·61	8·24	5·20	(5·00)	(5·00)	4·05	4·37	3·71
4'0"–4'6"	10·40	10·40	12·06	13·73	12·44	11·48	10·92	10·60	10·17	(9·78)	(9·05)	(8·10)	(8·32)
4'6"–5'0"	10·36	9·96	12·71	15·53	13·21	12·21	10·99	10·47	10·01	9·78	9·05	8·10	8·32
5'0"–5'6"		...	(12·71)	...	(13·21)	(12·60)	(11·80)	(11·50)	(11·18)	(10·74)	(9·96)	(9·18)	(9·07)
5'6"–6'0" ...		...	(12·71)		(13·21)	(13·00)	(12·70)	(12·50)	12·36	11·71	10·86	10·27	9·92
6'0"–6'6" ...			(12·71)		(13·21)	(13·00)	(12·70)	(12·50)	(12·55)	(12·32)	(11·80)	(11·12)	(11·31)
6'6"–7'0" ...			(12·71)		(13·21)	(13·00)	(12·70)	(12·50)	12·75	12·94	12·73	11·98	12·69
7'0"–7'6"	...												
7'6"–8'0"	...	...				...			12·82	11·21	13·14	12·65	12·67
8'0"–8'6" ...	...												
8'6"–9'0" ...										11·67	13·50	13·41	13·42

STATEMENT NO. X.

Ratio of Water to Surface, 19th March, 1906.

		0"–3"	3"–6"	6"–9"	9"–1'0"	1'0"–1'3"	1'3"–1'6"	1'6"–1'9"	1'9"–2'0"
Weight of 1 c.c. of soil in situ (grams)		1·302	1·316	1·354	1·393	1·346	1·258	1·273	1·210
Water per 1 c.c. of soil, 1 gram = 1 c.c.	W.	·2122	·1912	·2052	·2583	·3269	·2841	·2388	·1780
Sq. cm. of surface of 1 gram of soil		1119	1707	1956	2399	3441	3060	2360	1646
Sq. cm. of surface of 1 c.c. of soil = S.		1847	2247	2649	3342	4633	3850	3005	1991
$\frac{W}{S} = R \times 10^4$		11·49	8·51	7·75	7·73	7·06	7·38	7·95	8·94

		2'0"–2'3"	2'3"–2'6"	2'6"–2'9"	2'9"–3'0"	3'0"–3'6"	3'6"–4'0"	4'0"–4'6"	4'6"–5'0"
Weight of 1 c.c. of soil in situ (grams)		1·311	1·298	1·255	1·191	1·256	1·385	1·462	1·427
Water per 1 c.c. of soil, 1 gram = 1 c.c.	W.	·1871	·2015	·2304	·1976	·1116	·2307	·3331	·3318
Sq. cm. of surface of 1 gram of soil		1478	1535	1597	1618	802	1641	2184	1976
Sq. cm. of surface of 1 c.c. of soil = S.		1937	1993	2004	1928	1007	2279	3194	2820
$\frac{W}{S} = R \times 10^4$		9·66	10·10	11·50	10·25	11·08	10·12	10·43	11·77

STATEMENT NO. XI.

Ratio of Water to Surface, 2nd April, 1906.

		0"–3"	3"–6"	6"–9"	9"–1'0"	1'0"–1'3"	1'3"–1'6"	1'6"–1'9"	1'9"–2'0"
Weight of 1 c.c. of soil in situ (grams)		1·402	1·430	1·454	1·350	1·254	1·232	1·243	1·297
Water per 1 c.c. of soil, 1 gram = 1 c.c.	W.	·1528	·2129	·2097	·2822	·2884	·2146	·2026	·1631
Sq. cm. of surface of 1 gram of soil		1402	1663	2206	2886	3138	2782	2406	1541
Sq. cm. of surface of 1 c.c. of soil = S.		1966	2378	3208	3896	3935	3427	2991	1999
$\frac{W}{S} = R \times 10^4$		8·91	8·95	6·54	7·24	7·33	7·14	6·77	8·16

		2'0"–2'3"	2'3"–2'6"	2'6"–2'9"	2'9"–3'0"	3'0"–3'6"	3'6"–4'0"	4'0"–4'6"	4'6"–5'0"
Weight of 1 c.c. of soil in situ (grams)		1·298	1·304	1·300	1·260	1·294	1·291	1·462	1·380
Water per 1 c.c. of soil, 1 gram = 1 c.c.	W.	·1282	·1184	·1353	·1778	·2666	·1874	·3332	·3190
Sq. cm. of surface of 1 gram of soil		1228	869	932	1287	1760	1339	2356	1996
Sq. cm. of surface of 1 c.c. of soil = S.		1594	1164	1212	1623	2277	1729	3445	2756
$\frac{W}{S} = R \times 10^4$		8·04	10·17	11·16	10·96	11·71	10·84	9·67	11·58

Statement No. XII.

Ratio of Water to Surface, 19th July, 1906.

	0"–3"	3"–6"	6"–9"	9"–1' 0"	1' 0"–1' 3"	1' 3"–1' 6"	1' 6"–1' 9"	1' 9"–2' 0"	2' 0"–2' 3"	2' 3"–2' 6"	2' 6"–2' 9"	2' 9"–3' 0"	3' 0"–3' 6"	3' 6"–4' 0"	4' 0"–4' 6"	4' 6"–5' 0"
Weight of 1 c.c. of soil in situ (grams)	1·383	1·416	1·317	1·266	1·244	1·335	1·436	1·265	1·307	1·289	1·341	1·305	1·317	1·387	1·460	1·458
Water per 1 c.c. of soil, 1 gram = 1 c.c. = W.	·2731	·2900	·2911	·2947	·3079	·3307	·3599	·2911	·2751	·2777	·3715	·4065	·3127	·3522	·3862	·4073
Sq. cm. of surface of 1 gram of soil	1812	1982	2587	2676	3076	3089	2871	1827	1246	1119	1247	1569	1179	2357	2316	1931
Sq. cm. of surface of 1 c.c. of soil = S.	2506	2806	3407	3388	3827	4124	4123	2311	1629	1442	1672	2049	1553	3269	3381	2815
$\frac{W}{S}$ = R × 10⁶ ...	10·90	10·34	8·54	8·65	8·05	8·02	8·73	12·60	16·89	19·26	22·22	19·84	20·14	10·77	11·42	14·47

Statement No. XIII.

Ratio of Water to Surface, 19th September, 1906.

	0"–3"	3"–6"	6"–9"	9"–1' 0"	1' 0"–1' 3"	1' 3"–1' 6"	1' 6"–1' 9"	1' 9"–2' 0"	2' 0"–2' 3"	2' 3"–2' 6"	2' 6"–2' 9"	2' 9"–3' 0"	3' 0"–3' 6"	3' 6"–4' 0"	4' 0"–4' 6"	4' 6"–5' 0"
Weight of 1 c.c. of soil in situ (grams)	1·451	1·405	1·324	1·201	1·522	1·281	1·333	1·553	1·150	1·239	1·289	1·272	1·295	1·440	1·491	1·521
Water per 1 c.c. of soil, 1 gram = 1 c.c. = W.	·3256	·2874	·2926	·3100	·3184	·3249	·3508	·3495	·3618	·4091	·4149	·4013	·3988	·4325	·3985	·4234
Sq. cm. of surface of 1 gram of soil	1415	1740	2421	2792	2813	2822	2697	2405	1809	1815	1772	1424	773	2085	2295	1555
Sq. cm. of surface of 1 c.c. of soil = S.	2053	2445	3205	3605	3719	3615	3595	3206	2089	2249	2284	1811	1001	3002	3422	2365
$\frac{W}{S}$ = R × 10⁶	15·86	11·75	9·13	8·60	8·56	8·99	9·76	10·90	17·32	18·19	18·17	22·16	39·84	14·41	11·65	17·90

STATEMENT No. XIV.

Ratio of Water to Surface, 20th October, 1906.

	0"–3"	3"–6"	6"–9"	9"–1' 0"	1' 0"–1' 3"	1' 3"–1' 6"	1' 6"–1' 9"	1' 9"–2' 0"	2' 0"–2' 3"	2' 3"–2' 6"	2' 6"–2' 9"	2' 9"–3' 0"	3' 0"–3' 6"	3' 6"–4' 0"	4' 0"–4' 6"	4' 6"–5' 0"
Weight of 1 c.c. of soil in situ (grams)	1·316	1·254	1·319	1·373	1·369	1·170	1·379	1·337	1·311	1·245	1·286	1·276	1·275	1·317	1·458	1·436
Water per 1 c.c. of soil, 1 gram = 1 c.c. = W.	·2246	·2181	·2686	·3003	·3262	·2757	·3262	·3068	·2647	·2589	·3094	·3741	·2852	·2758	·3678	·3911
Sq. cm. of surface of 1 gram of soil	1608	1874	2823	3014	3112	3025	2692	2119	1476	1364	1419	1458	1404	1215	2234	1994
Sq. cm. of surface of 1 c.c. of soil = S.	2116	2351	3724	4138	4260	3540	3711	2967	1935	1698	1825	1835	1790	1600	3257	2864
$\frac{W}{S} = R \times 10^6$	10·60	9·28	7·21	7·26	7·66	7·79	8·79	10·30	13·70	15·20	16·90	20·40	15·90	17·20	11·30	13·60

STATEMENT No. XV.

Ratio of Water to Surface, 30th November, 1906.

	0"–3"	3"–6"	6"–9"	9"–1' 0"	1' 0"–1' 3"	1' 3"–1' 6"	1' 6"–1' 9"	1' 9"–2' 0"	2' 0"–2' 3"	2' 3"–2' 6"	2' 6"–2' 9"	2' 9"–3' 0"	3' 0"–3' 6"	3' 6"–4' 0"	4' 0"–4' 6"	4' 6"–5' 0"
Weight of 1 c.c. of soil in situ (grams) ...	1·324	1·470	1·176	1·336	1·345	1·340	1·324	1·331	1·260	1·253	1·287	1·283	1·317	1·333	1·433	1·382
Water per 1 c.c. of soil, 1 gram = 1 c.c. = W.	·210	·245	·192	·264	·304	·305	·283	·258	·181	·149	·157	·198	·324	·264	·350	·352
Sq. cm. of surface of 1 gram of soil ...	1527	1883	2115	2857	3485	3258	2690	2031	1362	1064	1109	1273	1774	1469	2517	1987
Sq. cm. of surface of 1 c.c. of soil = S. ...	2022	2767	2490	3817	4688	4365	3561	2703	1716	1333	1427	1633	2336	1958	3608	2747
$\frac{W}{S} = R \times 10^6$	10·38	8·86	7·72	6·92	6·49	6·98	7·96	9·53	10·56	11·17	11·02	12·12	13·87	13·49	9·69	12·81

Statement No. XVI.

Ratio of Water to Surface, 8th January, 1907.

	0"–3".	3"–6".	6"–9".	9"–1' 0".	1' 0"–1' 3".	1' 3"–1' 6".	1' 6"–1' 9".	1' 9"–2' 0".	2' 0"–2' 3".	2' 3"–2' 6".	2' 6"–2' 9".	2' 9"–3' 0".	3' 0"–3' 6".	3' 6"–4' 0".	4' 0"–4' 6".	4' 6"–5' 0".
Weight of 1 c.c. of soil in situ (grams) ...	1·333	1·410	1·280	1·281	1·311	1·253	1·339	1·333	1·305	1·270	...	1·338	1·312	1·314	1·496	1·447
Water per 1 c.c. of soil, 1 gram = 1 c.c. = W.	·1702	·1761	·1786	·2531	·3049	·2893	·2932	·2757	·2233	·1642	...	·2214	·2674	·1667	·3335	·3355
Sq. cm. of surface of 1 gram of soil	1465	1696	1718	2358	3295	2987	2826	3439	1926	1274	...	1493	1642	1095	2305	2004
Sq. cm. of surface of 1 c.c. of soil = S	1952	2391	2198	3020	4321	3743	3784	3252	2513	1618	...	1999	2155	1439	3448	2898
$\frac{W}{S} = R \times 10^4$	8·72	7·36	8·13	8·38	7·05	7·73	7·75	8·48	8·88	10·15	...	11·08	12·41	11·59	9·85	11·58

Statement No. XVII.

Ratio of Water to Surface, 15th February, 1907.

	0"–3".	3"–6".	6"–9".	9"–1' 0".	1' 3"–1' 6".	1' 9"–2' 0".	2' 3"–2' 6".	2' 9"–3' 0".	3' 3"–3' 6".	4' 0"–4' 6".	4' 6"–5' 0".	5' 6"–6' 0".	6' 6"–7' 0".	7' 6"–8' 0".
Weight of 1 c.c. of soil in situ (grams)	1·364	1·422	1·346	1·035	1·298	1·412	1·278	1·243	1·278	1·437	1,427	1·522	1·459	1·451
Water per 1 c.c. of soil, 1 gram = 1 c.c. = W. ...	·1974	·2188	·2065	·1651	·2965	·3139	·1540	·1987	·2010	·3257	·3208	·3958	·4087	·4107
Sq. cm. of surface of 1 gram of soil	1477	1748	2055	2048	4061	3088	1267	1476	1012	2614	2223	2801	3947	3679
Sq. cm. of surface of 1 c.c. of soil = S.	2014	2486	2765	2120	5273	4359	1620	1834	1294	3756	3173	4263	5759	5340
$\frac{W}{S} = R \times 10^4$	9·80	8·80	7·47	7·79	5·62	7·20	9·51	10·83	15·54	8·67	10·11	9·28	7·10	7·69

Statement No. XVIII.

Ratio of Water to Surface, 27th March, 1907.

	0"–3".	3"–6".	6"–9".	9"–1' 0".	1' 3"–1' 6".	1' 9"–2' 0".	2' 3"–2' 6".	2' 9"–3' 0".	3' 0"–3' 6".	3' 6"–4' 0".	4' 6"–5' 0".	5' 6"–6' 0".	6' 6"–7' 0".	7' 6"–8' 0".	8' 6"–9' 0".
Weight of 1 c.c. of soil in situ (grams) ...	1·328	1·276	1·402	1·504	1·482	1·297	1·017	1·084	1·199	1·457	1·391	1·493	1·550	1·484	1·283
Water per 1 c.c. of soil, 1 gram = 1 c.c. = W. ...	·1657	·1741	·2102	·3061	·3450	·2233	·1612	·1603	·1369	·3367	·3134	·3752	·4147	·3593	·3739
Sq. cm. of surface of 1 gram of soil ...	1451	1618	2274	3499	4162	2321	1390	1434	1045	2773	2238	3482	3371	3401	3661
Sq. cm. of surface of 1 c.c. of soil = S. ...	1926	2064	3188	5265	6166	3012	1383	1575	1207	4040	3122	5198	5226	5049	4700
$\frac{W}{S} = R \times 10^4$	8·60	8·43	6·78	5·81	5·59	7·41	11·66	10·31	11·34	8·33	10·04	7·22	7·93	7·13	7·96

Statement No. XIX.

Ratio of Water to Surface, 6th May, 1907.

	0"–3".	3"–6".	6"–9".	9"–1' 0".	1' 3"–1' 6".	1' 9"–2' 0".	2' 3"–2' 6".	2' 9"–3' 0".	3' 0"–3' 6".	3' 6"–4' 0".	4' 6"–5' 0".	5' 6"–6' 0".	6' 6"–7' 0".	7' 6"–8' 0".	8' 6"–8' 0".
Weight of 1 c.c. of soil in situ (grams) ...	1·373	1·448	1·366	1·359	1·380	1·296	1·396	1·339	1·327	1·311	1·439	1·445	1·535	1·500	1·535
Water per 1 c.c. of soil, 1 gram = 1 c.c. = W. ...	·1211	·1599	·1670	·2459	·2900	·1812	·1528	·1773	·0809	·1292	·2901	·3480	·4079	·4212	·4325
Sq. cm. of surface of 1 gram of soil ...	1447	1652	1989	3225	3554	1983	1491	1740	765	1437	2160	2757	4012	3703	3713
Sq. cm. of surface of 1 c.c of soil = S. ...	1988	2392	2718	4384	4965	2572	1947	2331	1016	1886	3110	3983	6158	5555	5700
$\frac{W}{S} = R \times 10^4$	6·09	6·68	6·15	5·61	5·91	7·04	7·86	7·60	8·96	6·85	9·33	8·74	6·62	7·58	7·5

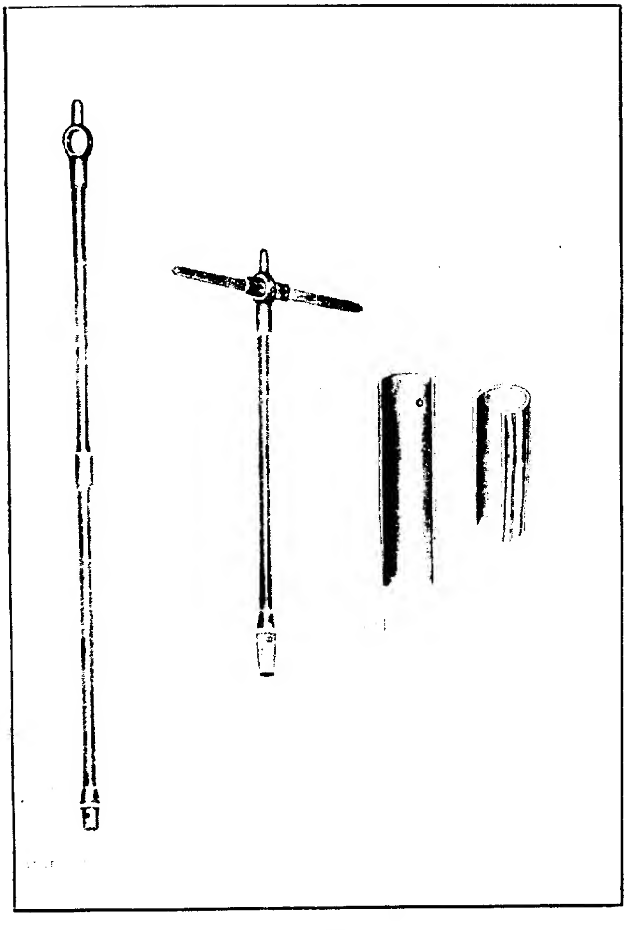


Fig. 2.—Boring tool.

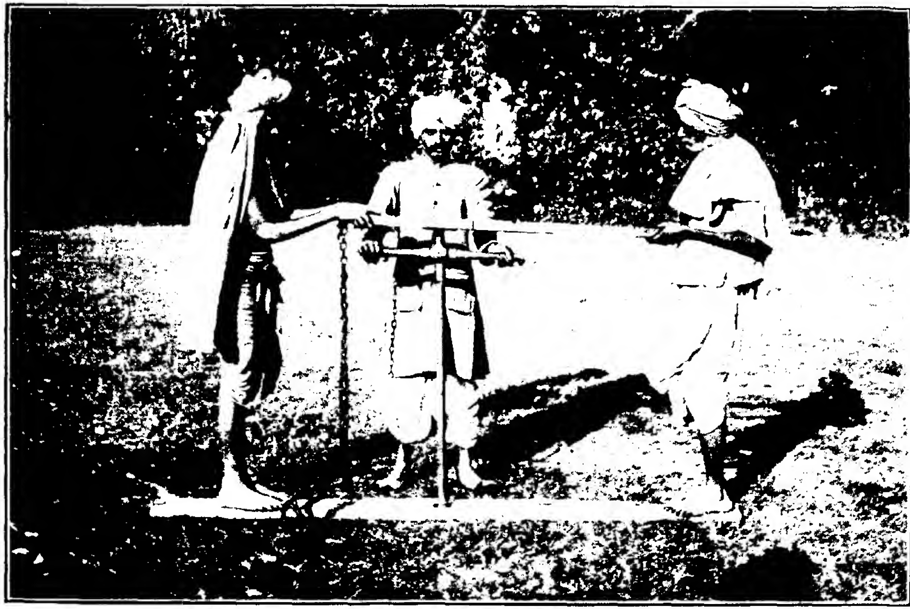


Fig. 3.—Boring tool in use.

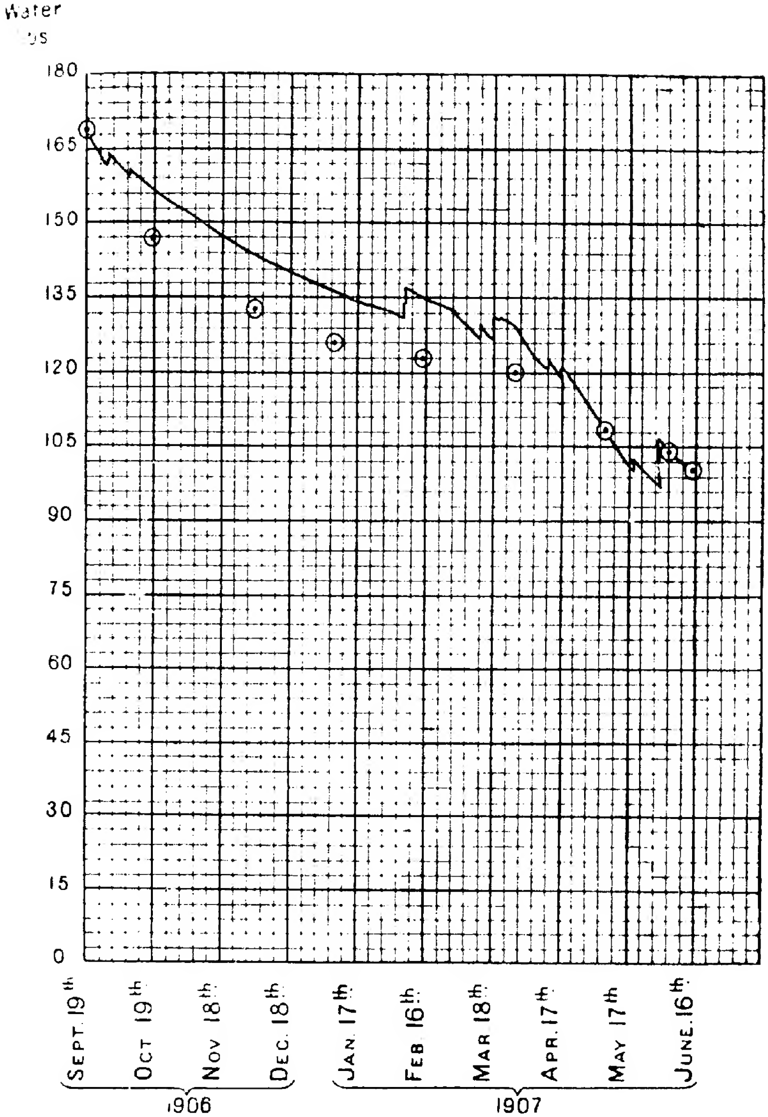


Fig. 4. Curve showing calculated amount of Water in Bare Soil, Sept. 1906 to June 1907.
⊙ Actual as determined.

Fig. 5. 2 hrs. sediment × 400 diam. .002 – .004 m.m.

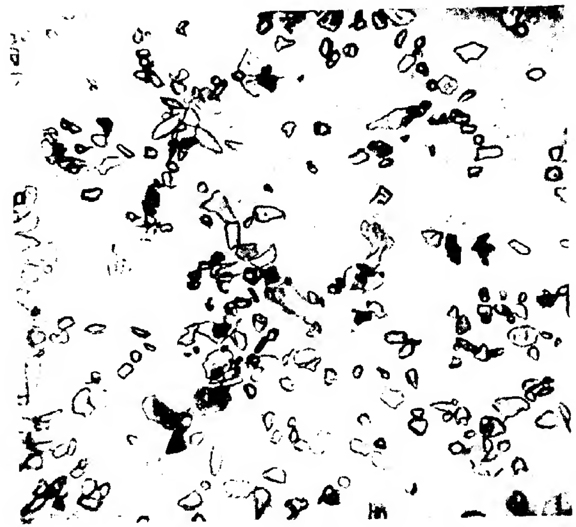


Fig. 6. 30 mins. sediment × 400 diam. .004 – .008 m.m.

Fig. 7.—10 mins. sediment × 400 diam. = ·008 – ·016 m.m.

Fig. 8.—75 secs. sediment × 400 diam. = ·016 – ·032 m.m.

PREFACE.

In the course of some investigations on soil gases, and the available plant food in soils, which are in progress in the Chemical Section of the Agricultural Research Institute at Pusa, more accurate information was required on the concentration of calcium carbonate and carbonic acid in water than exists in the literature of this subject. Accordingly, a series of measurements have been made, and the data, together with the general formula expressive of the concentration, are published in this memoir.

I desire to take the opportunity of expressing my obligation to Dr. Morris W. Travers, F.R.S., for kindly advice in regard to the interpretation of some of the results.

J. W. L.

PLATE I

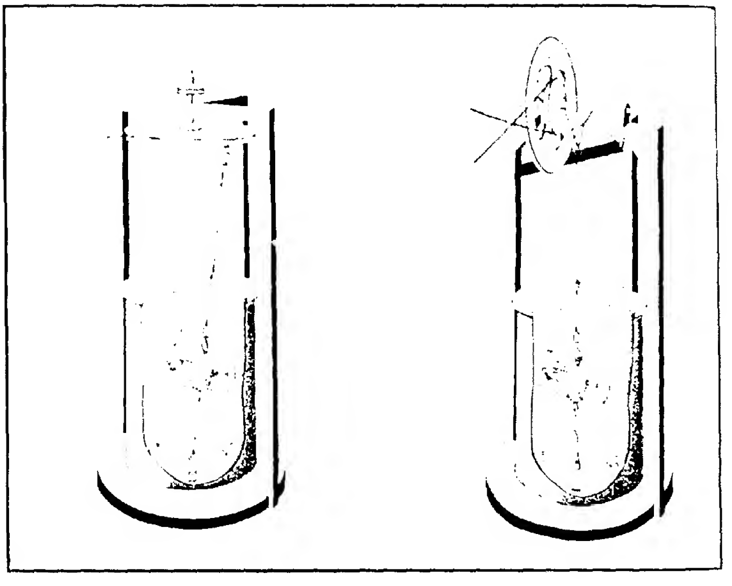


Fig. 1.   Fig. 2.

THE SYSTEM WATER, CALCIUM CARBONATE, CARBONIC ACID.

BY

J. WALTER LEATHER, Ph.D., F.I.C., F.C.S.;

AND

JATINDRANATH SEN, M.A., F.C.S.

ALTHOUGH numerous determinations have been made of the amount of calcium carbonate in solution in presence of carbonic acid, the literature contains only two communications on the subject which attempt to show the relation obtaining at atmospheric pressure between the concentration of the calcium carbonate, or bicarbonate, in solution and the partial pressure of the carbon dioxide in the gas phase. The one is by Th. Schloesing who in 1872 published* the results of a series of determinations on this relationship at 16°C. The other communication is by Treadwell and Reuter who published† the results of a series of determinations on the same subject, conducted at 15°C. Apart from the fact that the concentrations obtained in these two investigations differ widely from each other, and the uncertainty which consequently existed as to which was the more reliable, we required correct information for temperatures up to about 40°C. for the assistance of the other work which has been briefly referred to in the Preface.

It is of interest to refer to the methods employed in each of these investigations, because the accuracy of the data must depend in a great measure on this. It is obvious that whether carbonic acid is brought into contact with calcium carbonate

* *Compt. Rend.*, 74 (1872), 1552; and *Jour. Chem. Soc.*, 25 (1872), 788

† *Zeits. f. anorg. Chemie*, XVII (1898), p. 170 et seq.

and water, or conversely whether a solution of "calcium bicarbonate" is exposed to an inactive gas, the reaction is a slow one, and equilibrium will only be attained in a comparatively brief period if the contact between the several phases is intimate. Schloesing pumped air containing known amounts of carbon dioxide through water containing calcium carbonate in excess for six or seven days at constant temperature (16 C), when he considered that equilibrium had set in. He says "Quand l'équilibre est établi dans la dissolution, c'est-à-dire après six ou sept jours,.. ......" (p. 1554), but does not explain how he ascertained that equilibrium was established. Unless equilibrium had actually occurred, his concentration would tend to be too low in comparison with the partial pressure of the CO_2. Schloesing considered that the solution consisted of calcium carbonate of the same concentration as pure water would contain at 16 C, carbonic acid of the same concentration as pure water would contain at 16 C. and under the partial pressure of the system, and calcium bicarbonate of the concentration which is demanded by the formula*

$$x^m = ky$$

Where x = the partial pressure of the gaseous CO_2 and $m = \cdot 37866$.

A comparison between our data and those of Schloesing may be here suitably made in so far as this is possible.

Partial pressure of CO_2 in gas. P.	Schloesing. t = 16 C. $CaCO_3$.	excess CO_2.	Leather and Sen. t = 15°C $CaCO_3$.	excess CO_2
		milligrammes per 100 c.c		
1·4	22·3	12	..	...
1·6	...	...	19·3	15·2
1·7	...	.	23·8	13·5
5·0	36·0	25·0	...	...
6·8	...	...	44·5	32·7
13·6	...	...	72·3	56·0
25·4	66·3	78·1		...
31·6	...	...	105·0	111·7
41·7	78·7	115·4	...	...

* Compt. Rend., 75 (1872), 70 and Jour. Chem. Soc., 25 (1872), 880.

The differences at low concentrations are only small, but at higher concentrations, ours are considerably greater than Schloesing's.

Treadwell and Reuter exposed a solution of calcium carbonate in carbonic acid to air in large bottles, which were *stationary*, and considered that the system had attained equilibrium when no further change in the composition of the gas phase was noticed. The vessels had a capacity of about 20 litres and were about half full of liquid. Thus they adopted the slowest possible method devisable for the end in view: for although the solution near the surface of the liquid might be expected to approach a state of equilibrium with the gas fairly quickly, the "bicarbonate" in the remainder of the liquid could only arrive at the surface by diffusion. As a result, their data for the concentration might be expected to be too high in comparison with the partial pressure of the CO_2. In fact, they seem to have recognised this defect, for they say "Auch hier ist in erster Linie das Erhalten einer Durchschnittsprobe von Wichtigkeit, denn es ist klar, dass das Wasser nicht in jedem Höhenschicht gleichmässig seine absorbierte Kohlensäure abgiebt; am meisten Gas verliert die oberste, am wenigsten die unterste Schicht" (p. 173). This necessarily implies an admission that the solution was not in equilibrium and consequently detracts much from the reliability of the method. The following comparison may be made between the concentrations as found by these authors and ourselves.

Partial pressure of CO_2 in gas. P	Treadwell and Reuter t = 15°C. $CaCO_3$.	excess CO_2.	Leather and Sen. t = 15°C. $CaCO_3$.	excess CO_2.
			milligrammes per 100 c.c.	
·3	77·1	18·1		–
1·7	–	–	23·8	13·5
2·0	82·2	60·5	—	–
6·8	108·3	134·0	11·5	32·7
9·9	——	——	62·7	45·6
10·0	115·6	207·8	– –	–

This comparison sufficiently exhibits the great divergence between our results and those of Treadwell and Reuter and

illustrates the necessity of providing for very intimate contact between the two phases in all such work.

It was early recognised by us that the greatest care must be adopted in order to obtain even approximate equilibrium. Schloesing provides only a verbal explanation of his apparatus in his communication, and in our hands at least the aspiration of carbon dioxide and air, through water containing calcium carbonate in suspension, showed that the contact was very imperfect and equilibrium could not be obtained in any short time. On the other hand, if an aqueous solution of calcium carbonate in carbonic acid be *agitated* with air, the reaction proceeds rapidly and equilibrium sets in in the course of two or three hours. The reverse change, namely, the solution of calcium carbonate, when shaken with water and air containing carbon dioxide, proceeds materially more slowly, and must also depend on the fineness of the carbonate; if it is freshly precipitated, equilibrium sets in in the course of three or four hours, but if the particles are larger, the process is more protracted; simple boiling of the precipitate is sufficient to make a material difference in this respect. Had the necessary apparatus been at our disposal, we would have preferred to employ both reactions, but practically our experiments had to be completed during the working day, and consequently, although a number of determinations have been made from $CaCO_3+CO_2$, we have depended on the results of those which have proceeded from the solution + air, because equilibrium could be attained so much more quickly.

Methods of analysis used.—Before describing the special apparatus which has been employed for the investigation, it will be convenient to mention what analytical methods were used. The carbon dioxide in the gas phase was determined gasometrically and the concentration expressed as a percentage; the water vapour was naturally included as a part of the gas. The calcium was determined by titration of the solution, after filtering off the insoluble carbonate, with dilute acid, methyl orange being used as indicator. The "free" carbonic acid was determined by boiling the (unfiltered) liquid and absorbing in soda lime.

The method of obtaining equilibrium between the several components.—After some preliminary work, a number of experiments were made with a vessel which contained the solution, excess of calcium carbonate and air. This vessel was provided with a tap by means of which (*inter alia*) momentary communication could be made with the atmosphere. It was held in a water bath of constant temperature. Periodically (every 10 to 15 mins.) it was taken out and the liquid agitated. Some time after no further alteration of pressure could be perceived, the vessel was attached to a gas burette, and while a sample of the gas was withdrawn, mercury was allowed to flow in, thus preventing any serious alteration of pressure. Then, samples of the solution were withdrawn for the determination of the calcium carbonate and carbonic acid. We considered the apparatus defective simply because intimate contact between gas and liquid was only ensured during the brief period of agitation. A second apparatus which we devised is shown in plate No. I, fig. 1, in which a Woulff's bottle A served as the reaction vessel. The horizontal pulley C revolved and carried the Woulff's bottle in a circular path, but since the latter was prevented from revolving, the liquid was dashed against the end of the bottle at each revolution of the pulley.

Fig. 2 in the plate illustrates the apparatus with which we made all the later determinations. A Woulff's bottle A again serves as the reaction vessel, but in place of a circular motion, the latter is vertical; the clamp D holding the bottle is attached by an India-rubber cord to the bottom of the water bath B; when the crank C is turned down, the rubber is slack; when it becomes horizontal, the rubber is just tight, and naturally becomes stretched while the crank moves through the upper semi-circle. Consequently the bottle receives a jerk at every revolution of the pulley. The bottle is provided with a long capillary tube E and stop cock which admits of re-establishment of normal pressure by communication with the outside atmosphere. This stop cock was opened frequently at first and somewhat less often during the later stages of the reaction. Equilibrium was assumed to have set in when no change of pressure could be perceived on opening

this stop cock; the agitation was, however, continued for some two hours longer in order to secure as complete a change as possible. After this the bottle was removed, attached to a gas burette, mercury run in at F and gas withdrawn at E. The samples of solution were then immediately taken for estimation of dissolved carbonic acid and calcium oxide. The calcium oxide employed for the solution of "bicarbonate" was obtained by burning a sample of very good marble.

The solid phase consists of $CaCO_3$ only.—In order to determine whether the solid phase in the system $CaCO_3$, CO_2, water contained any bicarbonate, two experiments were made. The separation of the solid for direct examination without decomposition of any bicarbonate (if such existed) appeared to us impossible, and recourse was consequently had to the following indirect method. A solution of calcium carbonate in carbonic acid was prepared and then agitated with air so as to produce equilibrium. Two portions of the liquid were then boiled and the carbon dioxide, which was evolved, determined. The one portion included the precipitated carbonate; the other was filtered rapidly into the boiling flask. The results are as follows:—

	CO_2 evolved from 100 c.c. solution without filtering off solid.	after removal of solid.
	grms.	grms.
I	·1261	·1211
II	·0837	·0760

In each case slightly less CO_2 was obtained after separation of the precipitate, which might be urged as evidence that the precipitate contains some small amount of bicarbonate, but we consider such a conclusion unwarranted. We had no means of executing the filtration in an atmosphere of the same concentration of carbon dioxide gas as had been in equilibrium with the solution, and were compelled to expose the liquid to the laboratory atmosphere. Such exposure would necessarily cause a certain amount of the dissolved carbonic acid to pass into the air, and it was anticipated that less carbonic acid would be found in the filtered than in the unfiltered solution. Since the difference

between the two determinations is so small, we consider the absence of the bicarbonate from the solid phase is proved.

Whilst writing this memoir we have seen the records of two series of experiments which have been made to ascertain the existence of solid calcium bicarbonate. In the first of these Cameron and Robinson* determined the relation between pressure and concentration of carbonic acid in the presence of calcium carbonate and water at 0 C. up to 4·5 atmospheres, and found that the one increased with the other. Had a bicarbonate formed, the pressure would have remained constant during its formation, and they accordingly conclude that no solid bicarbonate is formed. In the second series of experiments Keiser and McMaster† precipitated a solution of calcium chloride with ammonium bicarbonate, both solutions being first reduced to 0 C. The precipitate was rapidly filtered and washed without any appreciable rise of temperature being permitted: this precipitate was then found to have the formula $CaCO_3$ 1·75 H_2CO_3. They also examined the solution which had been first agitated with air, and found that the relation between the calcium carbonate and carbonic acid to be the same as in the solid. Since the temperature 0 C is so much below what we have employed in our experiments, it is unsafe to criticise this work on the basis of our own, but judging from the concentrations of the two constituents in solution as found by Keiser and McMaster, it seems likely that these solutions were far from being in equilibrium with the air, and that had they been brought into equilibrium, not only would the concentrations have fallen very considerably, but the ratio between $CaCO_3$ and H_2CO_3 would have altered materially. The presence of the carbonic acid in the precipitate is not so readily accounted for, but it seems reasonable to suggest that it was present as a solid solution rather than as a part of a definite chemical compound. It seems to us at least proved that at the temperature 15°C. and upwards calcium bicarbonate cannot exist in the solid state.

* *Jour. Phys. Chem.*, 1908, XII, 561.

† *Jour. Am. Chem. Soc.*, 1908, XXX, 1714.

Mode of expressing the results.—Apart from any consideration of the existence or otherwise of the bicarbonate, it is much simpler for all practical purposes to consider the components of the solution to be calcium carbonate and carbonic acid respectively and to calculate each as a function of the partial pressure.

Therefore, from the data obtained at each temperature the constants in the expression

$$C^n = kp$$

have been evaluated for $CaCO_3$ and CO_2 respectively.

On plotting the values of these *constants* against the temperature, they were found to be slightly irregular as was indeed anticipated, but as they showed no indication of lying on curves, it has been assumed that they are linear functions of the temperature, and that the value of n may be expressed as $\alpha + \beta t$, that of log k as $\gamma + \delta t$. Hence the concentration of either constituent may be expressed thus :—

$$\log C_{(CaCO_3)} = \frac{(\gamma + \delta t) + \log p}{\alpha + \beta t}$$

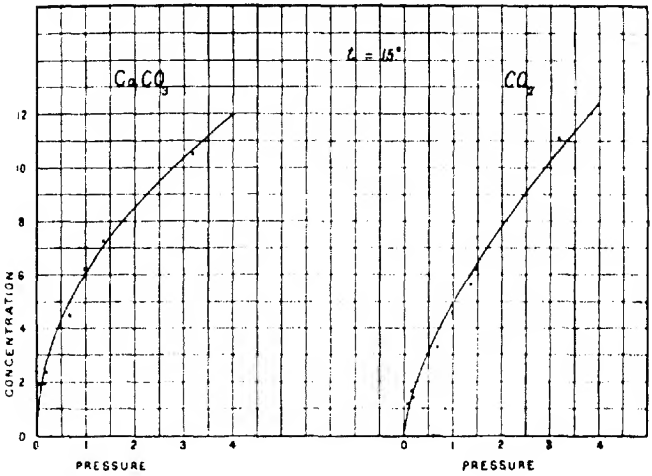
$$\log C_{(CO_2)} = \frac{(\gamma + \delta t) + \log p}{\alpha + \beta t}$$

It is naturally understood that the values of α, β, γ and δ are different in the two cases. Their values are as follows :—

	for $CaCO_3$	for CO_2.
α	1·5897	1·2133
β	·0310	·0200
γ	2·2853	1·4213
δ	·0256	·0096

In the following pages are set out for each temperature the experimental data, and those calculated from the general formulæ, in charts and tabular statements.

PLATE II.



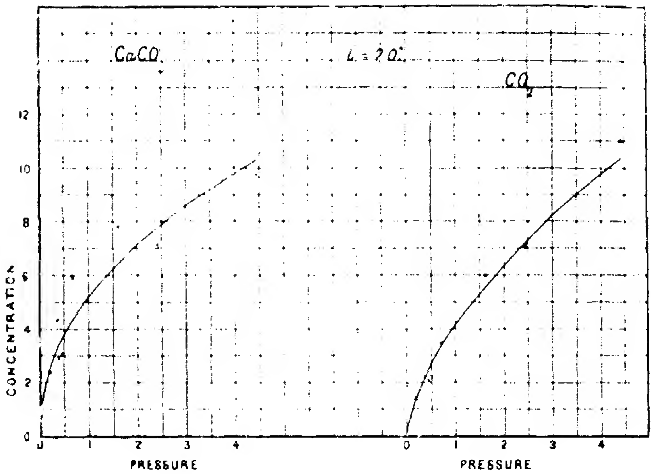
TEMPERATURE 15 C.

The subjoined statement shows the concentration of $CaCO_3$ and CO_2 *in m.grms. per* 100 *c.c.* as experimentally found and as calculated from the general formula.

For $CaCO_3$, n = 2·0554, log k = 2·6693.
For CO_2, n = 1·5127, log k = 1·5659.

P.	$CaCO_3$.		CO_2.	
	Found.	Calculated.	Found.	Calculated.
·8	19·3	17·9	11·7	9·35
1·5	19·3	24·2	15·2	14·2
1·7	23·8	25·8	13·5	15·4
6·8	44·5	50·6	32·7	38·5
9·9	62·7	60·8	45·6	49·2
13·6	72·3	71·0	56·0	60·8
14·6	68·6	73·5	62·3	63·7
31·6	105·0	107·0	111·7	106·2

PLATE III.



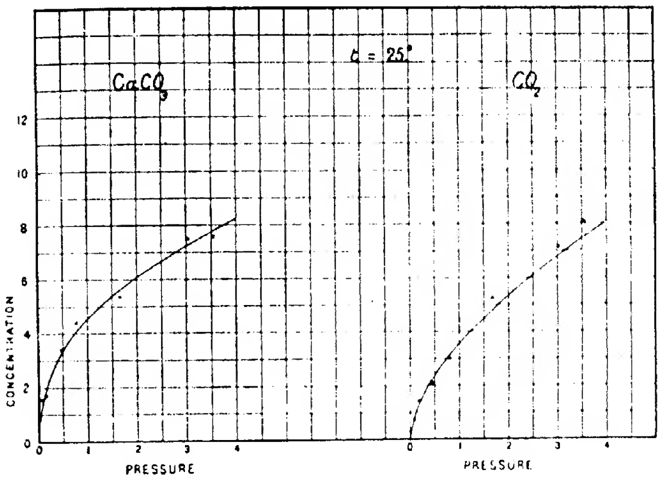
TEMPERATURE 20 C.

The subjoined statement shows the concentration of CaCO and CO_2 *in mgrms per* 100 c.c. as experimentally found and as calculated from the general formula.

For $CaCO_3$, n = 2·2107, log k = 2·7973.
For CO_2, n = 1·6125, log k = 1·6141.

P.	CaCO Found.	CaCO Calculated.	CO_2 Found.	CO_2 Calculated.
1·8	23·9	26·0	11·9	14·4
3·6	13·2	32·9	22·2	22·2
3·9	29·1	34·1	21·7	23·3
4·8	30·2	37·1	22·2	26·5
6·9	58·4	44·2	34·6	33·2
16·0	78·0	64·6	59·9	56·0
24·1	70·9	77·7	70·4	72·1
44·3	97·9	102·4	110·9	105·2

PLATE IV.



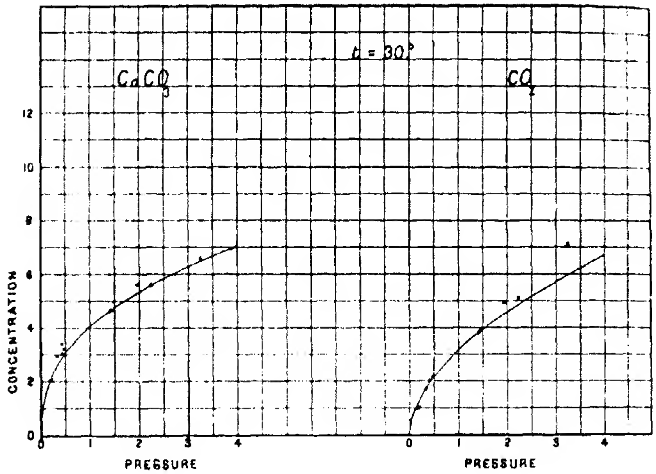
TEMPERATURE 25 C.

The subjoined statement shows the concentration of $CaCO_3$ and CO_2 *in m.grms. per* 100 *c.c.* as experimentally found and as calculated from the general formula.

For $CaCO_3$, n = 2·3659, log k = 2·9253.
For CO_2, n = 1·7124, log k = 1·6623.

P.	$CaCO_3$. Found.	$CaCO_3$. Calculated.	CO_2. Found.	CO_2. Calculated.
·7	15·9	14·8	9·1	7·6
1·6	17·7	21·0	11·1	12·3
4·6	34·1	32·9	20·8	22·8
7·8	44·6	41·4	30·1	31·0
16·5	53·9	56·4	52·2	48·1
30·1	74·3	72·6	71·5	68·2
55·5	75·5	78·0	80·3	75·2

PLATE V.



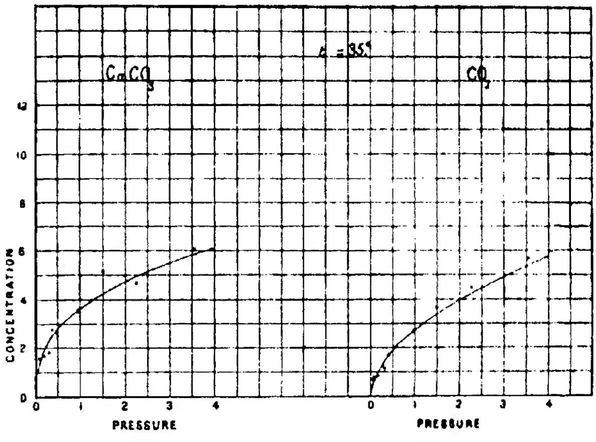
Temperature 30 C.

The subjoined statement shows the concentration of $CaCO_3$ and CO_2 *in m.grms. per* 100 *c.c.* as experimentally found and as calculated from the general formula.

For $CaCO_3$, $n = 2{\cdot}5211$, $\log k = 3{\cdot}0533$.
For CO_2, $n = 1{\cdot}8122$, $\log k = 1{\cdot}7104$.

P.	$CaCO_3$ Found.	$CaCO_3$ Calculated.	CO_2 Found.	CO_2 Calculated.
1·8	20·0	20·5	10·1	12·2
3·3	29·5	26·1	16·9	17·0
4·2	33·9	28·7	19·9	19·4
4·4	30·2	29·2	18·5	19·9
4·7	31·6	30·1	21·0	20·7
14·1	47·1	47·3	38·5	38·8
19·6	56·1	53·0	49·6	45·4
22·2	55·9	55·6	51·4	48·6
32·2	65·5	64·4	71·0	59·7

PLATE VI.



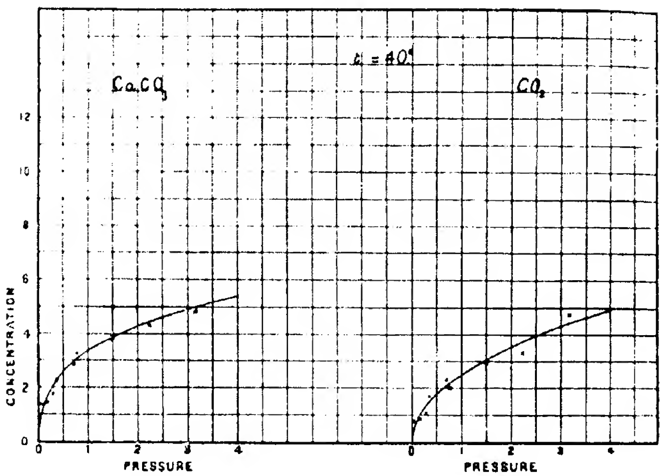
TEMPERATURE 35 C.

The subjoined statement shows the concentration of $CaCO_3$ and CO_2 *in m.grms. per* 100 *c.c.* as experimentally found and as calculated from the general formula.

For $CaCO_3$, n = 2·6764, log k = 3·1813.
For CO_2, n = 1·9120, log k = 1·7586.

P.	$CaCO_3$. Found.	$CaCO_3$. Calculated	CO_2. Found.	CO_2. Calculated.
·7	15·7	13·5	9·0	6·9
1·6	16·8	18·4	9·3	10·6
2·9	18·2	23·0	11·3	14·5
4·0	27·5	25·9	17·8	17·2
9·6	35·7	36·0	26·9	27·2
15·0	51·6	42·5	37·6	34·3
22·6	46·4	49·6	45·2	42·5
35·4	60·0	58·5	56·8	53·7

PLATE VII.



TEMPERATURE 40 C.

The subjoined statement shows the concentration of CaCO and CO_2 *in m.grms. per* 100 *c.c.* as experimentally found and as calculated from the general formula.

For $CaCO_3$, n = 2·8316, log k = 3·3093.
For CO_2, n = 2·0118, log k = 1·8068.

P.	$CaCO_3$ Found	$CaCO_3$ Calculated.	CO_2 Found.	CO_2 Calculated.
·6	13·6	12·3	7·8	6·1
1·7	14·3	17·8	8·5	10·3
2·9	17·5	21·5	10·6	13·4
3·5	23·2	23·0	16·9	14·8
7·0	28·4	29·3	23·4	20·8
7·7	32·5	30·5	20·0	21·8
14·9	38·4	38·5	29·3	30·3
22·2	42·7	44·4	33·3	36·9
51·7	48·0	50·0	47·6	44·1

CONCLUSION.

The information contained in this Memoir on the solubility of calcium carbonate in the presence of carbonic acid is obviously a step towards the possession of more exact knowledge than we at present possess regarding the concentration of lime in the aqueous solution in the soil. Although impossible to obtain this solution from the soil in an unaltered state, it is feasible to obtain specimens of the gases, and from a knowledge of their composition to make deductions regarding the amount of carbonic acid in solution and hence also regarding the concentration of calcium and other carbonates. Our prospective work naturally includes a study of the relations subsisting between the carbonic acid and other carbonates commonly present in the soil, in regard to which such information may be lacking. The conclusion of this work should place a general formula in our hands with the aid of which our object may be attained.

Although only one step has been achieved, it has been possible to already apply it towards a study of the solubility of soil phosphates in the presence of calcium carbonate and carbonic acid. The solubility of soil and rock minerals has been repeatedly shown to be much greater in the presence of carbonic acid than in pure water, and accordingly this constituent has been considered to be an important natural solvent of plant food in the soil. Such experiments have been, however, uniformly made with pure carbonic acid in such concentration as can rarely if ever occur in arable land. On the other hand if soils are treated with water, calcium carbonate and carbonic acid in such proportions as occur naturally, the result may be a quite different one. For example, a number of soils have been placed under these circumstances and in no case was it found that the solubility of the phosphate was increased; generally indeed the effect was a somewhat reduced solubility.

PREFACE.

This Memoir provides information regarding the amount of water transpired by some of the commonly cultivated crops, when grown in Behar soil; it is anticipated that similar information regarding transpiration in other soils may be collected in the course of another year.

Nearly the whole of the work has been done by Messrs. K. S. Viswanatha Iyer, B.A., and A. Viswanatha Iyer, B.A., two of the Assistants in the Chemical Section of this Institute, and I desire to take this opportunity of acknowledging the care they have bestowed upon it.

J. W. L.

PUSA,
10th *April*, 1909.

WATER REQUIREMENTS OF CROPS IN INDIA.

BY

J. WALTER LEATHER, Ph.D., F.I.C., F.C.S.,

Imperial Agricultural Chemist.

INTRODUCTION.

IN Chapter XI of their report, the Indian Irrigation Commission, 1901-03, remark: "In the course of our investigations we have been struck with the small amount of attention which appears to have been given by the Departments of Agriculture and Public Works to matters connected with the application of water to cultivated crops. At present most of the information which can be had on these points has to be taken from papers published by the Agricultural Bureau in America." It is indeed hardly necessary to dilate on the general importance of the subject in India where an efficient water-supply is, over at least very large areas, probably of greater importance than any other condition which appertains to its agriculture.

The subject of the water-supply to crops may, apart from rainfall or questions of irrigation systems, be conveniently subdivided under six heads:

(1) the moistness of a soil for the purposes of germination and initial growth:

(2) the total quantity of water required by a crop;

(3) the period of growth during which a crop requires most water;

(4) the amount of water which is contained in a soil;

(5) the proportion of this which is available to crops;

(6) the effect on *the development of a crop* of varying proportions of water in any specified soil.

The information contained in this Memoir relates to the *second* and *third* of these subjects.

The vegetable physiologist has devoted attention largely to the organs of plants which chiefly control transpiration. He has compared the process with the relative abundance of the stomata, has estimated the relative activity in this respect of the upper and lower side of the leaf, the activity of the parenchyme, the function of hairs and the like. In such investigations the water transpired is commonly referred to the leaf area, or to a unit area of leaf, or equal parts of a plant have been employed and the quantities of water transpired in equal periods of time have been compared. But for the end which we have in view, namely, an estimate of the water required by crops, such investigations can only have an indirect value. Experiments have also been made on the effects of light of different refrangibility, of temperature, and of humidity. Whilst the first of these has no direct bearing on our subject, the second and third are important, but a knowledge of their influence during the whole growing period is required rather than at individual times. Indeed, experiments have been so commonly made for short periods of time and so frequently with parts of plants of non-agricultural interest, rather than with the more important field crops, that much of what has been published on transpiration of water becomes of little direct use to us. It will be well to emphasise the limits of the subject we are to deal with. It is simply "How much water is transpired by our several field crops ?" and "during what period does the crop require the principal portion of this water ?" Several experimenters have estimated the former, whilst as to the latter question, although deductions may be made from published data, attention does not appear to have been directed to it specially.

As regards the total quantity of water involved, it is to be anticipated that a large plant or crop will transpire more water than a small one of the same kind. Consequently it becomes essential to adopt a mode of expressing our quantities which will make them applicable to all general cases.

Those who have dealt with the subject which we have in hand, have uniformly referred *the water transpired to the weight of dry plant produced*, and have expressed the relation between these two quantities as a *Ratio*, namely, the parts by weight of water transpired per 1 part of dry plant substance produced. This is the *Transpiration Ratio*. Thus, if the transpiration ratio of wheat were stated to be 500, it would imply that for each pound or ton of wheat crop grown, including the grain, chaff and straw, (but not the root) 500lbs. or tons of water would be transpired. It is then a simple matter to calculate the quantity per acre: for instance, say a wheat crop weighed 4,000lbs. per acre, and the transpiration ratio were 450, then the weight of water transpired per acre would be $4{,}000 \times 450 = 1{,}800{,}000$lbs. or $\frac{1{,}800{,}000}{2{,}240} =$ 804 tons or, since an acre of water 1″ deep weighs (approximately) 227,000lbs. $\frac{1{,}800{,}000}{227{,}000} = 7{\cdot}95$ inches. This is the simplest mode of stating the information and is adopted in this publication in so far as the first of our two subjects is concerned.

Reference may now briefly be made to the work of others. The transpiration ratio of field crops has been determined at four Agricultural Stations, namely, at Rothamsted (1848) by Lawes, at Dhame (1867—72) by Hellriegel, at Munich (1876) by Wollny, and at Wisconsin (1891-92) by King.

Their results may be suitably summarised thus :—

STATEMENT I.

	Lawes Ratio.*	Hellriegel Ratio.†	Wollny Ratio.‡	King Ratio.§
Wheat	217	338		
Barley	257		774	393
Oats		376	665	522
Rye		353		
Maize			233	310
Beans	209	282		
Peas	259	273	416	477
Clover	269	310		453
Buckwheat		363	646	
Colza		329	912	

* Jour. R. Agricultural Soc. V (1850)

† Grundlagen des Ackerbaues, p. 622, et seq.

‡ Einfluss der Pflanzendecke und Beschattung auf die physikalische Eigenschaften und Fruchtbarkeit des Bodens, p. 125.

§ Rep. Wisconsin Expt. Stn., 1894, p. 248

From the papers which these authors published it appears that the amount of water transpired is very large, that it is greatest during the period of rapid leaf development and until the fruit is formed after which it declines, and that it is affected by temperature, atmospheric humidity and the supply of plant-food.

It is evident, however, that, inasmuch as Indian climatic conditions are so widely different from those of the Agricultural Stations mentioned, the above transpiration ratios would in any case require careful check by experiments made in India before they could be employed with any confidence here. And this is the more desirable because of the very considerable differences which occur in the values of the published ratios.

The question as to whether plants transpire more, or less, water in the tropics than in Europe, has indeed formed the subject of a number of experiments and discussions since 1892. Haberlandt, from experiments made at Buitenzorg in Java and at Graz in Holland, concluded that the transpiration is much less in the "moist-warm" climate of West Java than in middle Europe. Against this opinion Gitlay, Burgerstein, Holtermann and others have quoted experiments which contradict such a conclusion. It seems that all the observations related to amounts of water transpired during short intervals of time such as a couple of hours, and were for the most part referred to the area of leaf surface involved; also that many of the experiments were made with parts of plants. The limitation of the work has been fully recognised by Burgerstein who says (page 173) "dass es nicht angeht, die in absentia solis für ein paar Tage ermittelte transpiration abgeschnittener Zweige oder Blätter von ein paar Pflanzenarten für die tatsächliche Jahresleistung eines ganzen Vegetations gebietes zu substituieren." (*Trans.*: that it is not legitimate to substitute for the actual yearly requirement of a whole vegetable region, the transpiration of isolated twigs or leaves of a couple of plant varieties, which has been ascertained in the absence of direct sunlight during a couple of days). It is obvious that the factors which control the water requirements of any particular crop are so numerous and the value of each so

difficult to determine with even approximate precision, that it seems unreasonable to deduce it for one country from observations made in another of entirely different climate. The data which we have obtained at Pusa do in fact show that the total water requirement of some of the crops grown during the moist period of the S. W. monsoon is distinctly smaller than those grown during the cold weather, and thus support in part Haberlandt's argument, but it is equally certain that the corresponding requirements of other crops grown at the same period are much larger. The nature of the plant is an important factor.

For several years records of the amount of water which plants, specimens of our field crops, transpire throughout their period of growth have been maintained at Pusa by means of "pot-cultures," and comparison of these data showed that they were so regular that, apart from other evidence, they might properly be accepted as a means of calculating the total quantity of water required. It will probably be most convenient to the reader if the subject-matter is divided as follows:

(*a*) method employed :

(*b*) data obtained ;

(*c*) examination of the data with a view to establishing the effect of various influencing factors.

Method Employed.

Pot-cultures.—The Pot-culture House at this Institute and its adjuncts have been described in Memoir No. 3 (Chem. Series) and it will therefore suffice if details of the method followed are given.

The cultivation jars.—These are glazed stoneware and have the following dimensions :

Size.	Diameter, inches.	Depth, inches.	Soil capacity, kilos. (Approx.)
A	9	12	14
B	9	16	22
C	9	22	29
D	12	16	31
E	12	22	56

Filling the jar.—The soil is always damped before being packed into the jar, because experience has shown that the water subsequently added becomes distributed much more uniformly if this procedure is adopted than if the soil is packed in air-dry. As regards the degree of moistness, discretion has to be used, for soils vary within wide limits in the amount of water required to make them moist; but, roughly speaking, sufficient water is carefully worked into the soil to make it just adhere together when pressed in the hand, without running the risk of it "puddling." Some soils are packed into the jars by pressing with the fist, others such as the Black cotton soil, are best only shaken into the jar. After filling the damped soil into the jar, water is added in quantities of about half a litre per day until the desired quantity has been introduced.

Mode of adding water.—In these experiments the water was always added by means of unglazed earthenware cylinders of about 2″ diameter and from 6″ to 10″ deep, provided with small holes in the bottom and lower part of the sides. These cylinders are fixed in position in the centre of the soil when filling the jar, so that the upper edge coincides approximately with that of the jar. By this means the surface soil remains loose, friable, and nearly air-dry, and cracking is thus avoided. The direct loss of water from the soil surface is at the same time much reduced. Experiments which have been made to test this latter point have shown that the loss of water from this cause has been reduced to about one-third by the use of these cylinders of what it would have been had the water been added at the surface of the soil.

In some soils, however, experience has shown that the surface becomes air-dry to such a degree by this method of watering, that the germination of the seed and the initial development of the young plant are interfered with, and consequently in such cases water is added at the surface until the plant is established, after which water is best supplied by the cylinders. The question naturally arose as to whether the root development occurred principally in the immediate neighbour

head of the cylinder. It was suspected that this might take place just where the water was introduced, but examination of the root systems has shown that the principal development is at the bottom of the jar, or at least below the cylinder and fully as much at the sides of the jar as near the cylinder. No particular accumulation of root has been found about these cylinders.

The water employed.—Clean well water has been used throughout.

Addition of fertilizers.—Wherever fertilizers are used, these are added either in the dry state to the air-dry soil before it is damped for filling, or the substance is dissolved in the water used for damping the soil.

Sowing seed.—From ten to twenty seeds are usually sown at regular space intervals immediately the jars are filled with soil.

Thinning.—After the seed has germinated and the plants fairly established, they are reduced in number and again further reduced a few days later to a small number, such as three or four; these are allowed to mature. This "thinning out" of the plants has been always (except in the first and second seasons) completed before the amount of water transpired became of material consequence. In the first and second seasons when this was not done, the thinned out plants were weighed and allowance for the water they had transpired was made in the final calculations.

Weighing.—The jars have been weighed *every morning* throughout the whole period of growth.

In each case the weight of jar, soil and water are known and these together form the "standard weight"; where the weight of the plant is so considerable that this should be included in order to avoid any serious error, an estimate of it is made and the "standard weight" increased accordingly. Usually this is unnecessary.

After recording the weight of the jar, the difference between this and the standard weight gives the weight of water transpired by the plant and lost by the soil during the preceding 24 hours, and this quantity of water is added so that the standard moistness of the soil is reinstated.

Control jars of soil.—The water lost from a jar of soil with plants growing in it is necessarily the sum of that transpired by the plants and that lost directly by evaporation from the soil. Our object is to estimate the former quantity.

Most experimenters on the subject of transpiration have employed *covered* jars in order to reduce the direct loss from the soil to a minimum. Thus Lawes placed glass plates, having holes in them for the plants to grow through, over the soil and cemented them to the edge of the jar. Hellriegel also in his later work employed close covers.

This device has not been employed at Pusa. In our experiments over *100* cultivations have been maintained at one time, and it would not only have increased the cost of the apparatus very considerably to provide such covers, but would in practice have been all but impossible of application at the time of filling jars and sowing. A much more serious matter is, however, the fact that by covering up the surface of the soil, normal aeration becomes suspended; and although our information regarding the value to a growing crop, of aeration of agricultural land is most imperfect, the suspension of this process would throw a doubt on the value of the work. Finally, it was ascertained that the loss of water from the soil is very regular, and is so small in comparison with that transpired by a heavy crop, that sufficiently exact information as to its magnitude may be ascertained by maintaining jars of the same soil containing the same proportion of water as that employed in the series of cultures. The error only assumes material proportions in the case of small stunted plants, and, as will become evident, this is of small consequence.

The method adopted is briefly this. For each experiment (except during the first season) a jar of the same size containing the same soil has been maintained at the same degree of moistness throughout the period of growth and the daily loss of water registered against the total loss from the other jars of the series. For the experiments with a number of crops grown in the same soil *four* such jars (two of which were manured) were used.

Now it is not to be expected that the soil of a series of jars, even though all are filled alike with the same soil and maintained with the same proportion of water, will evaporate exactly the same amount of water, and the records of the four jars mentioned provide an index of this difference. For example, during the growing period of the Juar last year, June 15th to November 11th, these four jars lost 9·93, 10·68, 13·03, and 14·11 kilos respectively. (It may be mentioned here that these differences are not in any way due to the presence of manure in the soil.) The arithmetical mean of these is assumed to be the amount of water which has evaporated directly from the soil during the experiment. This method of estimating the factor is naturally not perfect but is more free from defects than any other and yields results which, at least for all well grown plants, are subject to an experimental error of not more than 5%. The corresponding error for poorly developed ones is larger, but the correctness of the transpiration ratio is not of great consequence in such cases.

Protection from rain. All jars are brought under cover in wet weather, as also at night.

Harvesting.—As the plants matured, they were cut off close to the root, air-dried, the seed finally separated, the whole weighed, and the remaining moisture determined. The weight of the material was then reduced to the dry state. In a few cases, (guar) cyamopsis psoralioides, and (arhar) cajanus indicus, some of the pods ripened before the remainder of the plant; in these the pods were removed as they ripened, so as to avoid losing them.

Effect of the sun's heat on the jars. One of the criticisms which have been made on the pot culture method for the determination of the transpiration ratio is that, since the jars are exposed to the direct rays of the sun, and the temperature of the soil is in consequence exposed to greater fluctuations than would occur in the field, a serious error is probable.

In order to test this question certain jars of maize in 1907 and of wheat in 1907-08 were maintained in large boxes surrounded with 5"—7" saw-dust throughout the period of growth: with which exception, however, the conditions

corresponded with other jars fully exposed. The results are summarised thus :—

STATEMENT II.

Protection.	Water in soil.	Manure used.	Dry crop, grms.	Water transpired, kilos.	R[illegible]
			Maize, 1907.		
Exposed to sun	20%	*Nil*	11·26	6·81	[illegible]
Protected		" ...	8·2	5·15	63[illegible]
Exposed to sun		Nitrate and phosphate ..	35·82	13·7	382
Protected		" "	40·95	17·30	428
			Wheat 1907 08.		
Exposed to sun	20	*Nil* ..	8·58	9·72	1133
Protected ...		"	8·33	8·45	1014
Exposed to sun .		Rape cake and phosphate	38·49	27·91	725
Protected .		" "	43·22	35·97	832

An examination of these data show that the exposure of the jars to the sun had no influence on the ratio.

Diurnal variation of water content in soil.—Although it was arranged to maintain a certain degree of moisture in the soil, it is obvious that as transpiration proceeds during the day, a decrease must occur in this proportion of water, and it is of interest to note how much this was. As in all such calculations, it is preferable to take maximum figures. Accordingly we may select instances from the largest and the most vigorous plants growing in the smallest jars. Such for example were the manured peas : these transpired about 1 kilo of water per day for a short time. The soil contained (at 20) 2·72 kilos of water, so that during the day the amount of water decreased to about 1·7 kilos when the percentage in the soil would be about 12½. This is naturally a great variation, but the experiments of the cold weather 1906-07 and the monsoon 1907 have shown that the transpiration ratio is not affected, within certain limits, by the amount of water in the soil, and those limits were not exceeded. But in most cases the diurnal percentage variation was considerably less than this, and in the large jars of soil it was only nominal.

PART II.

Details of Pot-cultures.

Inasmuch as a large part of the records obtained by pot-cultures lend themselves to tabular statement, this method has been here adopted and the chief data are so exhibited in the following pages. In most cases a chart is added showing the daily weight of water lost throughout the growing period together with its relation to the atmospheric humidity. Illustrations of most of the plants themselves are likewise added.

Apart from data, there are however several other matters which require explanation.

General synopsis of the experiments.—In the first season, the cold weather 1906-07, wheat was grown in Pusa soil in two sizes of jars. In each of these sets of jars three different proportions of water in the soil were maintained, and the jars of each of these sub-divisions were differently manured. It was intended to grow lucerne in two others, but the first seed used did not germinate, and in order to avoid losing a season, new lucerne was sown in only one set of the jars, and Cicer arietinum (Gram) in the other. The lucerne grew well at first, but failed later: the gram was more or less diseased. In the following monsoon period maize was selected for the experiments and was grown in Pusa soil. Here three sizes of jar were employed, three different proportions of water were maintained in each set and the soil of each sub-division was differently manured. An examination of the data thus obtained during two seasons seemed to indicate one or two general conclusions. The depth or quantity of soil employed, affects the size of the plant, and seemed to have a moderate influence on the transpiration ratio: the effect of different proportions of water in the soil was not appreciable. On the other hand, the effect of a fertilizer containing nitrate and phosphate had in both seasons a very marked influence on the ratio. Another marked difference was noticed between the transpiration ratio for wheat and maize respectively, the former being materially larger than the latter. During the next season, the cold weather

of 1907-08, it was decided to check the results obtained with wheat. For this purpose it was grown in Pusa soil in two sizes of jar; in each set two different proportions of moisture in the soil were maintained, and the soil of each subdivision was differently manured; in this case, however, oil cake was used instead of calcium nitrate or calcium cyanamide. These experiments fully substantiated the first in all important respects, and it was decided to enlarge the scope of the experiments particularly in two respects: firstly, to employ a variety of soils as different from one another as possible, in which the same plant would be grown; secondly, to employ half a dozen of the chief field crops, all of which would be grown in the same soil. The former list included, in addition to the highly calcareous Pusa soil, a black cotton soil, a soil containing an unusually high proportion of organic matter and two rather sandy soils. Details regarding this section of the investigation will be the subject of a future communication. The ratios obtained with maize during the monsoon were quite regular and indicated that the nature of the soil has either no influence or at most only a nominal influence on the transpiration ratio. The cold weather ratios, obtained with wheat, proved irregular in some respects and make it necessary to repeat this section of the work.

For the second section of the work a number of different crops were grown in Pusa soil. The plants employed were seven during the monsoon of 1908, namely, zea mais (maize), oryza sativa (rice), andropogon sorghum (the big millet juar), the two small millets, eleucine coracana (murwa, ragi) and paspalum scrobiculatum (kodo) and two pulses, cajanus indicus (arhar, tur) and cyamopsis psoralioides (guar). Similarly during the succeeding cold weather, 1908-09, seven other plants were included, namely, wheat, oats, barley, linseed, B. campestris (sarson), peas and cicer arietinum (gram). Regarding the general growth of the plants, the following brief remarks may be made:—In nearly all cases germination was regular. Most plants develop very well in the small jars (size A), but maize forms a conspicuous exception and does not form cobs

properly in these. As will be seen by reference to the data, this fact seems to have affected the transpiration ratio in only a moderate degree. The large millet juar, though it did better than maize, was not a really good specimen. But all the other plants, even the large pulse, arhar, have grown to great perfection. The latter grew 8 feet high and wheat about 4 feet high in the manured soil in these small jars.

Duplication of jars.—During the first three seasons no experiment was duplicated, dependence being placed on a single jar in each case, but the results obtained did in fact substantiate one another indirectly because several of the conditions, such as proportion of water in the soil, proved to exert no very great influence on the transpiration ratio. In the following seasons, the monsoon 1908 and the cold weather 1908-09, only one proportion of moisture was adopted in any one case, and duplication of jars was more necessary. An examination of the data show that such duplication is an advantage, but the number of cases where a serious difference in the result occurs is only very small. For the purpose of a ready comparison of the data, the statements have been arranged according to the nature of the plant, in the following order:—

Cold weather season	Wheat Barley Oats Linseed Sarson Peas Gram
Monsoon crops...	Maize Juar Rice Marwa Kodo Arhar Guar

The data for wheat which has been grown during three seasons are arranged chronologically; and the same has been adopted for maize which has been grown during two seasons.

The numbering of the plates and charts in this Memoir is such that the same number is given to the statement, the plate, and the chart of any one crop, and consequently some plate and chart numbers are absent from the Series; for example, there are no plates or charts corresponding to statements I and II; there is no chart No. III; there is no plate No. IX, etc.

STATEMENT III.

Triticum sat. (Wheat) 1906-07.

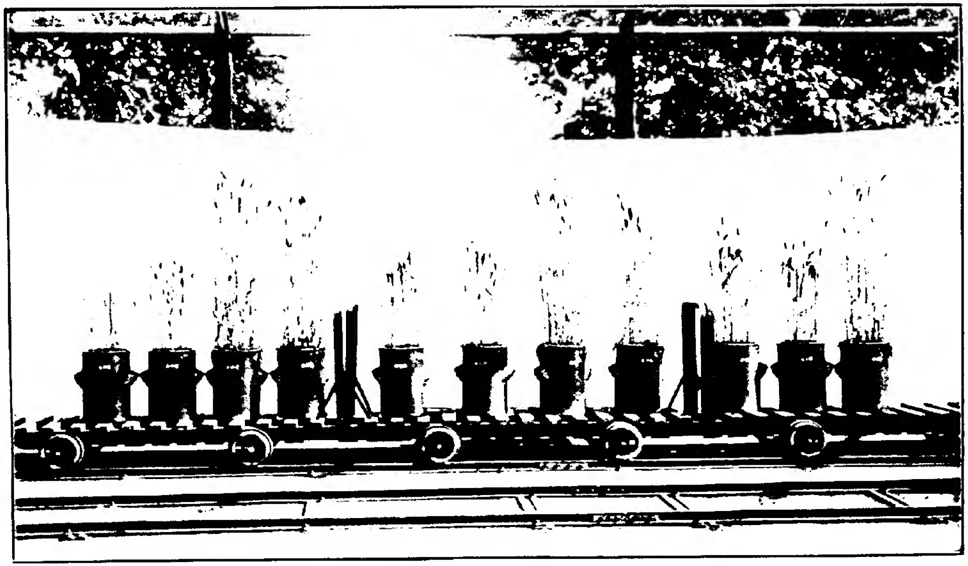
Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired Kilos.	Ratio.
101	A = 9" diam. × 12" deep.	About 15 kilos. of Pusa soil.	10	Nil	23·10·06	22·4·07	2·5	9·6	8·65	900
102			10	N	23·10·06	22·4·07	1·8	11·3	11·83	1,050
103			10	N + P	23·10·06	5·4·07	13·0	41·0	22·26	543
104			10	N + P + K	23·10·06	5·4·07	12·4	43·2	22·72	527
105			15	Nil	23·10·06	22·4·07	1·9	8·4	5·48	653
106			15	N	23·10·06	22·4·07	2·1	13·5	12·72	944
107			15	N + P	23·10·06	5·4·07	13·0	40·5	21·85	540
108			15	N + P + K	23·10·06	5·4·07	11·9	39·9	20·56	515
109			20	Nil	24·10·06	22·4·07	3·7	15·6	12·90	829
110			20	N	23·10·06	22·4·07	3·3	8·1	18·07	1,000
111			20	N + P	23·10·06	5·4·07	15·1	53·3	30·63	574
112			20	N + P + K	23·10·06	5·4·07	12·0	44·7	26·05	583

C = Ca $(NO_3)_2$ = ·005 grm. N; P = superphosphate = ·01 grm. soluble P_2O_5 and K = K_2SO_4 = ·005 grm. K_2SO_4 per 100 grm. soil.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired Kilos.	Ratio.
401	B = 9" diam. × 16" deep.	About 22 kilos. of Pusa soil.	10	Nil	24·10·06	22·4·07	3·9	16·2	15·25	941
402			10	N	24·10·06	22·4·07	2·1	14·9	12·41	806
403			10	N + P	24·10·06	5·4·07	23·3	72·3	42·91	593
404			10	N + P + K	24·10·06	5·4·07	15·[illegible]	50·2	30·82	614
405			15	Nil	24·10·06	22·4·07	4·8	22·0	23·32	1060
406			15	N	24·10·06	22·4·07	4·8	22·5	18·83	837
407			15	N + P	24·10·06	5·4·07	24·4	79·1	39·88	504
408			15	N + P + K	24·10·06	5·4·07	18·1	54·7	33·05	604
409			20	Nil	24·10·06	22·4·07	6·8	29·5	28·17	955
410			20	N	24·10·06	22·4·07	5·3	21·5	18·60	865
411			20	N + P	24·10·06	5·4·07	28·4	86·9	44·62	515

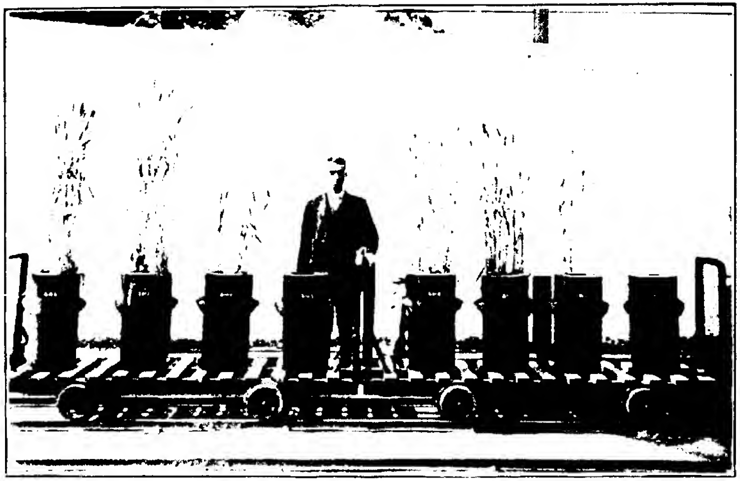
N = Ca CN_2 = ·005 grm. N per 100 grms. soil; P = superphosphate = ·01 grm. soluble P_2O_5
K = K_2SO_4 = ·005 grm. K_2O per 100 grms. soil.

PLATE III.



WHEAT, 1907.

PLATE IV



WHEAT, 1907-8.

504, 508. Oil Cake and Superphosphate.
503, 507. Oil Cake.
502, 506. No manure.

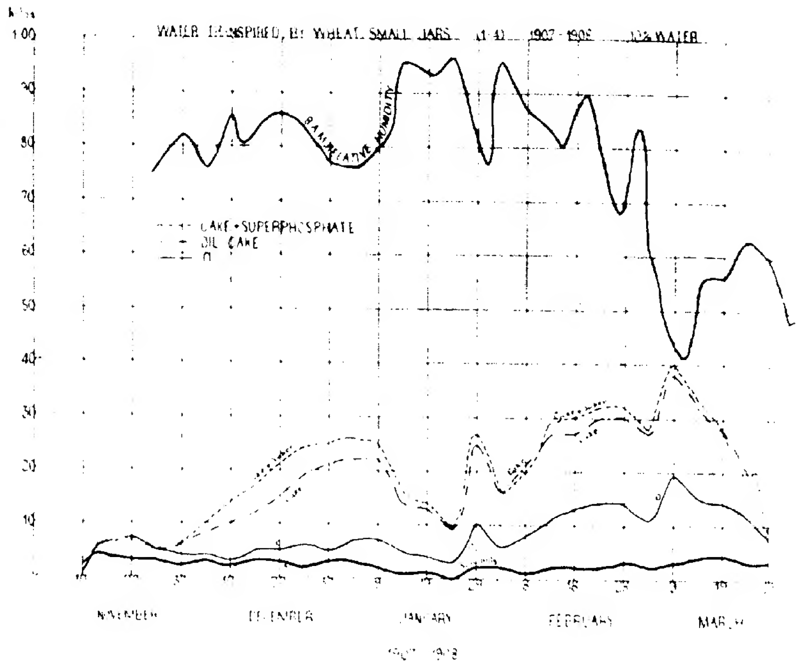
STATEMENT IV.

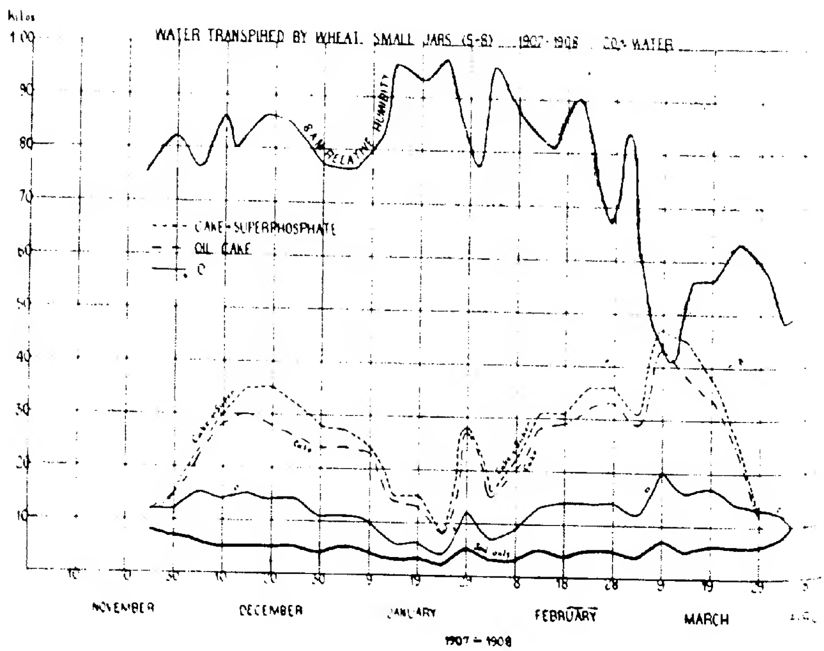
TRITICUM SAT. (WHEAT) 1907-08.

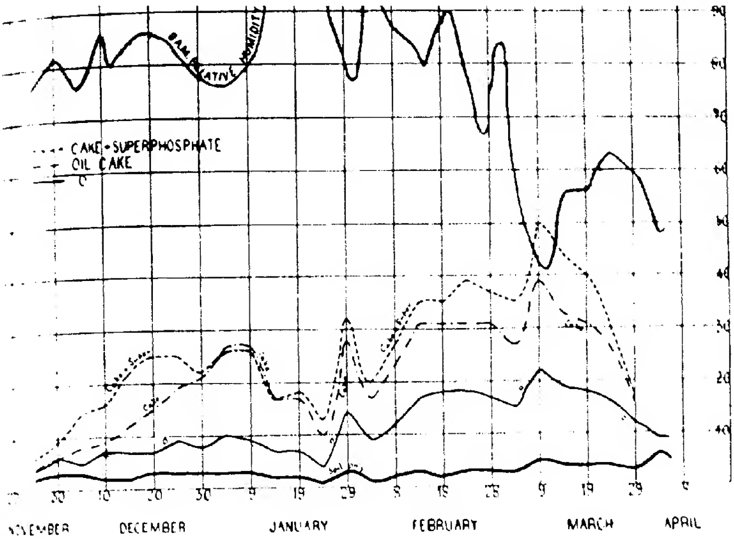
Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry Crop. Seed. Grms.	Dry Crop. Total. Grms.	Water transpired. Kilos.	Ratio.
1	A = 9" diam. × 12" deep.	About 15 kilos of Pusa soil.	10	Blank	Jar.				(3·13)	
2			10	Nil.	31-10-07	30-3-08	3·65	12·31	7·80	634
3			10	Rape cake	31-10-07	30-3-08	13·79	42·20	22·08	523
4			10	Rape cake and superphosphate.	31-10-07	30-3-08	14·66	42·85	24·15	571
5			20	Blank	Jar					
6			20	Nil.	31-10-07	6-4-08	1·79	8·58	9·72	1133
7			20	Rape cake	31-10-07	30-3-08	10·87	34·11	24·72	725
8			20	Rape cake and superphosphate.	31-10-07	30-3-08	12·71	38·49	27·91	725
501	C = 9" diam. × 22" deep.	About 29 Kilos of Pusa soil.	10	Blank	Jar.				(7·03)	
502			10	Nil.	30-10-07	6-4-08	5·02	16·5	11·49	696
503			10	Rape cake	30-10-07	30-3-08	15·19	47.84	23·92	500
504			10	Rape cake and superphosphate.	30-10-07	30-3-08	22·37	67·03	29·90	446
505			20	Blank	Jar.					
506			20	Nil.	30-10-07	6-4-08	4·83	23·31	19·14	821
507			20	Rape cake.	30-10-07	30-3-08	37·99	132·79	76·42	575
508			20	Rape cake and superphosphate.	30-10-07	30-3-08	33·55	120·44	60·87	505

The *Rape cake* used was equivalent to ·005 grm. N. per 100 grms. soil ; the superphosphate was sufficient to increase the phosphate in the manure to ·01 grm. soluble phosphoric acid per 100 grms. soil.

CHART IVa.

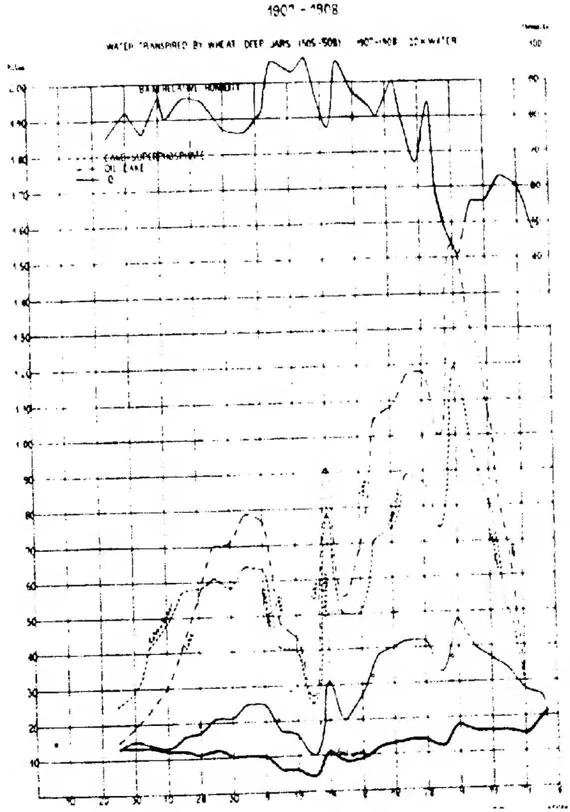

WATER TRANSPIRED BY WHEAT. SMALL JARS (1-4) 1907-1908
CAKE + SUPERPHOSPHATE
OIL CAKE
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH


WATER TRANSPIRED BY WHEAT. SMALL JARS (5-8) 1907-1908 20% WATER
CAKE + SUPERPHOSPHATE
OIL CAKE
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
1907 – 1908



BAM RELATIVE HUMIDITY
CAKE + SUPERPHOSPHATE
OIL CAKE
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL

1907 - 1908



CAKE + SUPERPHOSPHATE
OIL CAKE

STATEMENT V.

TRITICUM SAT. (WHEAT) 1908-09.

Jar No.	Jar size.	Soil per jar.	Water in soil, Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed, Grms.	Dry crop. Total, Grms.	Water transpired, Kilos.	Ratio.
	A = 9" diam. × 12" deep.	About 14 kilos. of Pusa soil.	20		Blank	jars			(8·49)	
115			20	Nil	5-11-08	23-3-09	4·09	17·02	14·43	848
116			20	Nil	5-11-08	23-3-09	4·56	16·81	14·83	882
117			20	N	5-11-08	23-3-09	3·23	17·80	15·24	856
118			20	N	5-11-08	23-3-09	4·08	15·77	11·19	709
119			20	N + P	5-11-08	23-3-09	20·06	64·92	34·82	536
120			20	N + P	5-11-08	23-3-09	18·72	62·05	29·73	479

N = $Ca(NO_3)_2$ = ·005 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART V.

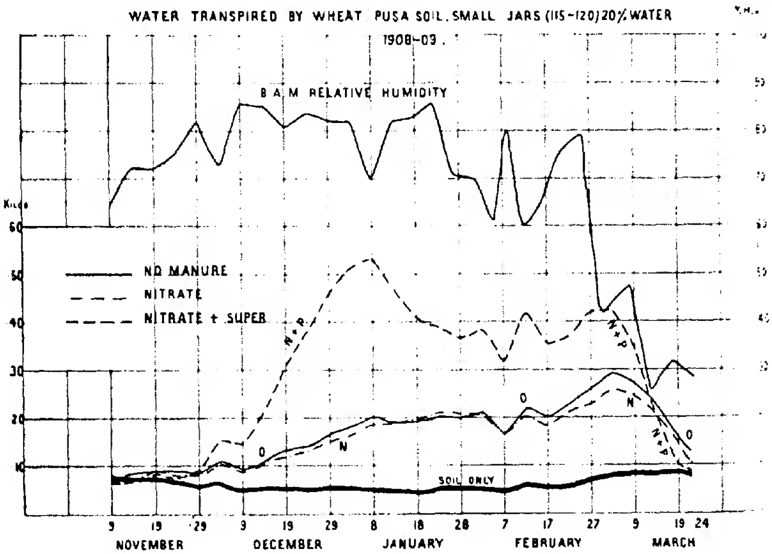
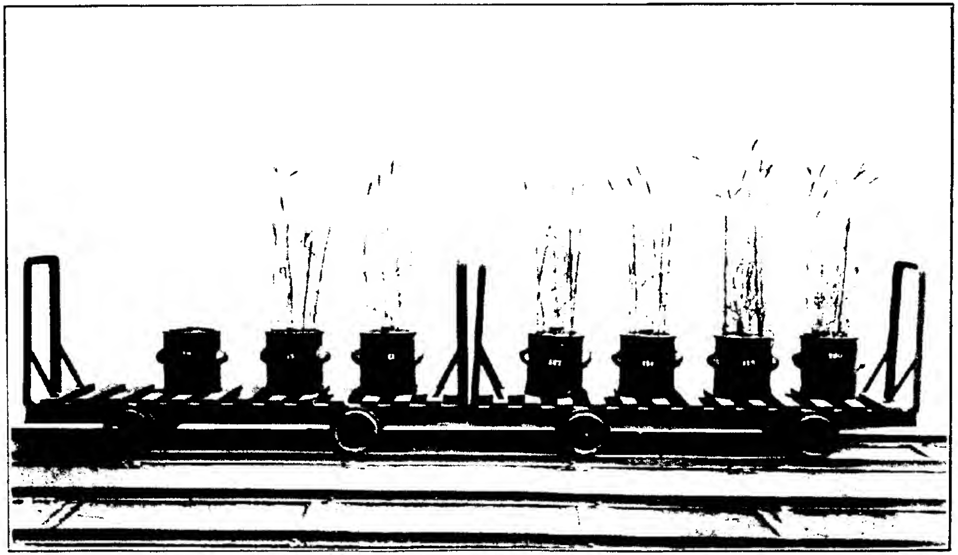


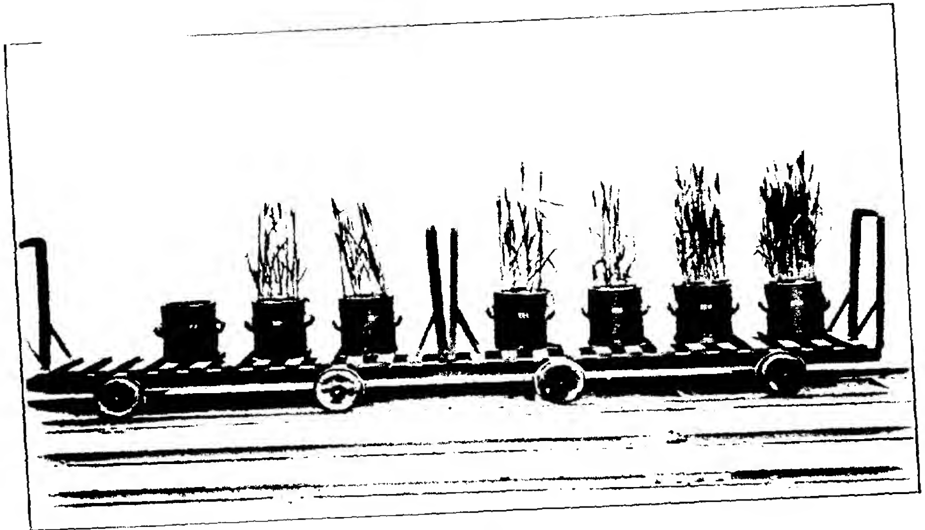
PLATE V



WHEAT, 1909.

115, 116. No manure.
117, 118. Nitrate only.
119, 120. Nitrate and Superphosphate.

PLATE VI.



BARLEY, 1908-9.

109, 110. No manure.
111, 112. Nitrate only.
113, 114. Nitrate and Superphosphate.

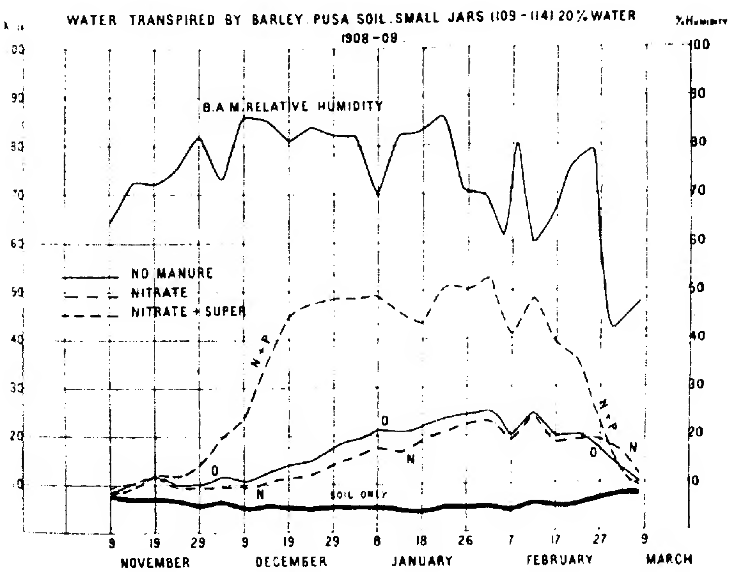
STATEMENT VI.

HORDEUM VULG. (BARLEY) 1908-09.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
	9" diam. × 12" deep.	About 14 kilos of Pusa soil.	20		Blank jars		...		(7·09)	...
109			20	Nil	2·11·08	8·3·09	9·5	19·9	13·52	679
110			20		2·11·08	8·3·09	9·5	19·2	12·97	676
111			20	N	2·11·08	8·3·09	8·7	28·6	12·08	422
112			20		2·11·08	8·3·09	7·5	26·0	11·32	435
113			20	N + P	2·11·08	8·3·09	29·9	61·1	31·58	517
114			20		2·11·08	8·3·09	34·8	80·8	36·07	446

N = $Ca(NO_3)_2$ = ·005 grm. N; P = superphosphate ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART VI.



STATEMENT VII.

Avena sat. (Oats) 1908-09.

Jar No.	Jar size.	Soil per jar.	Water in soil Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	[illegible]
	A 9″ diam. 12″ deep.	About 14 kilos of Pusa soil.	20		Blank jars		...	...	(8·04)	
83			20	Nil	21 10 08	8 3 09	2·65	5·66	6·32	1117
84			20	Nil	21 10 08	8 3 09	5·20	10·98	6·91	[illegible]
85			20	N	5 11 08	8 3 09	5·11	11·74	10·23	871
86			20	N	5 11 08	8 3 09	5·30	12·20	9·54	782
87			20	N + P	21 10 08	8 3 09	22·88	52·01	31·83	612
88			20	N + P	21 10 08	8 3 09	30·65	59·58	29·21	490

N = $Ca(NO_3)_2$ = 0·5 grm. N; P = superphosphate = 0·1 grm. soluble P_2O_5 per 1[illegible] grms. soil.

CHART VII.

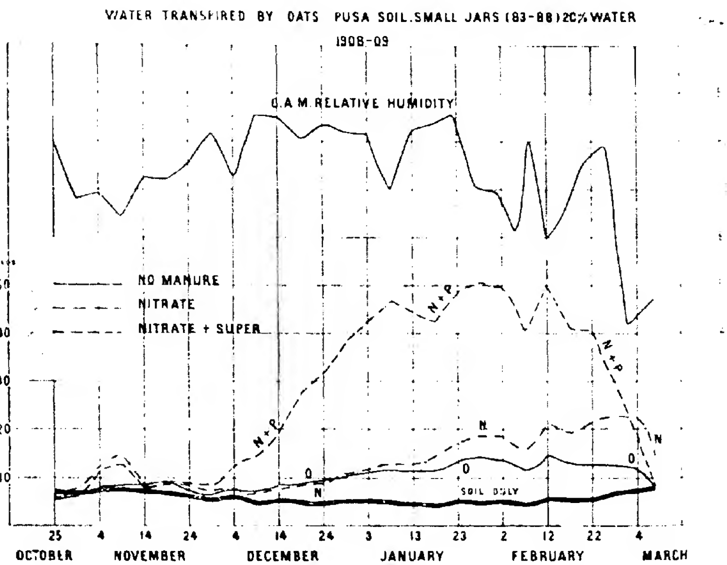
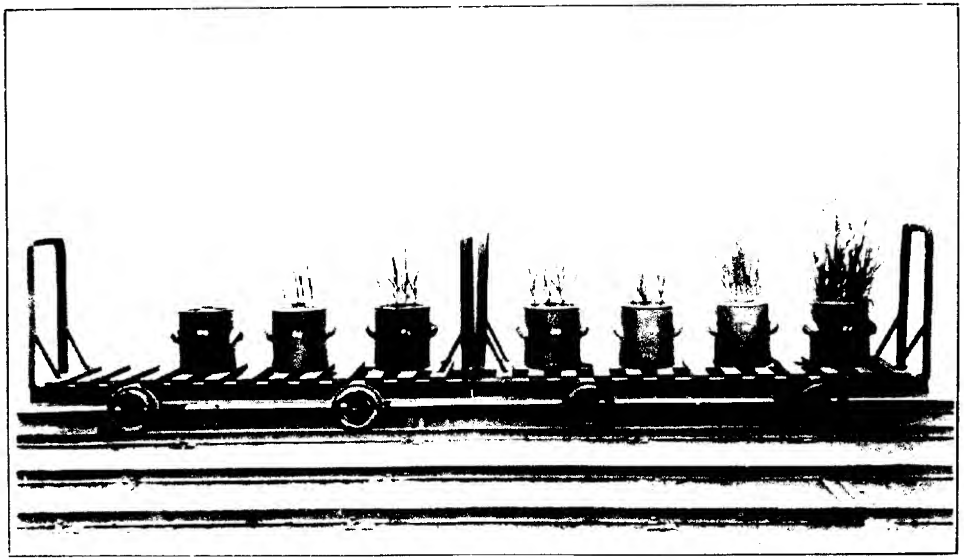


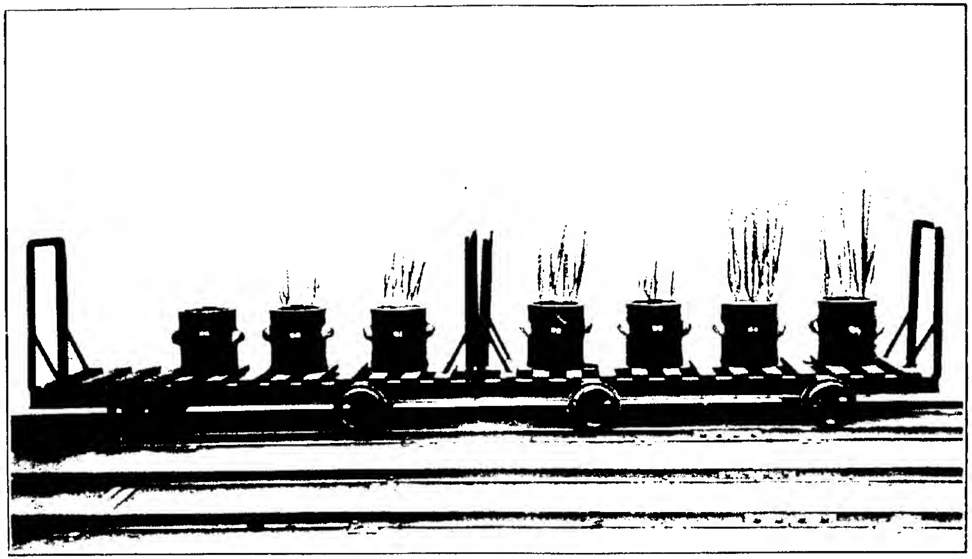
PLATE VII.



Oats, Row 9.

83, 84. No manure.
85, 86. Nitrate only.
87, 88. Nitrate and Phosphate.

PLATE VIII.



LINSEED, 1908-9.

90, 91. No manure.
92, 93. Nitrate only.
94, 95. Nitrate and Superphosphate.

STATEMENT VIII.

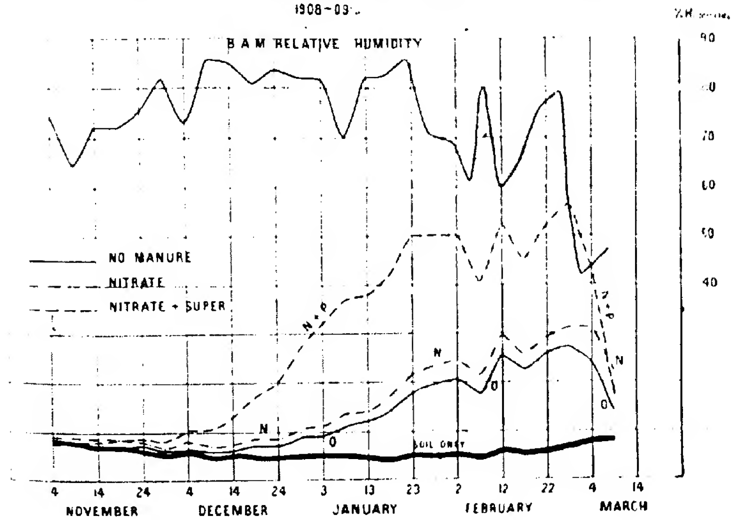
Guizotia abyss. (Linseed) 1908-09.

Jar No.	Jar size.	*Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
	A—9" diam. 12" deep.	About 14 kilos of Pusa soil.	20		Blank jars				(7·35)	...
90			20	Nil	2 11 08	9 3 09	1·91	7·18	8·84	1231
91			20	Nil	2 11 08	9 3 09	2·47	11·17	10·66	954
92			20	N	2 11 08	9 3 09	3·92	15·58	17·13	1099
93			20	N	2 11 08	9 3 09	2·00	7·35	9·53	1297
94			20	N + P	2 11 08	9 3 09	11·68	35·78	34·27	957
95			20	N + P	2 11 08	9 3 09	6·99	24·83	25·90	1043

N = $Ca(NO_3)_2$ = ·005 grm. N ; P = superphosphate ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART VIII.

WATER TRANSPIRED BY LINSEED PUSA SOIL SMALL JARS (90-95) 20% WATER 1908-09.



STATEMENT IX.

Brassica campestris (Sarson) 1908-09.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
^	A = 9" diam. 12" deep.	About 14 kilos of Pusa soil.	20	Blank jars			..	...	7·00 / 5·93	
76			20	Nil	20-10-08	23-1-09	1·65	5·69	4·10	719
77			20		20-10-08	23-1-09	1·93	6·07	4·60	754
78			20	N	20-10-08	23-1-09	4·36	14·05	12·52	888
79			20		20-10-08	23-1-09	6·88	19·81	14·82	748
80			20	N + P	20-10-08	3-2-09	7·06	23·94	15·40	644
81			20		20-10-08	3-2-09	16·43	55·88	33·82	605

N = $Ca(NO_3)_2$ = ·005 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART IX.

WATER TRANSPIRED BY SARSON . PUSA SOIL SMALL JARS (76-81) 20% WATER 1908-09

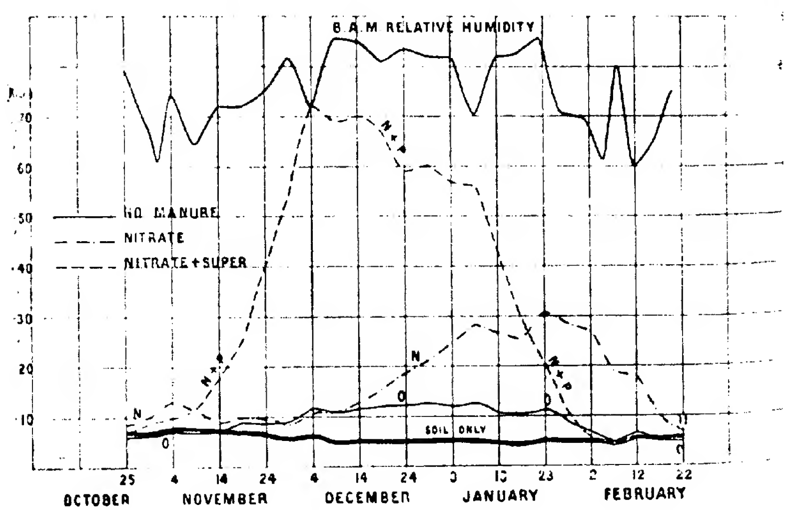
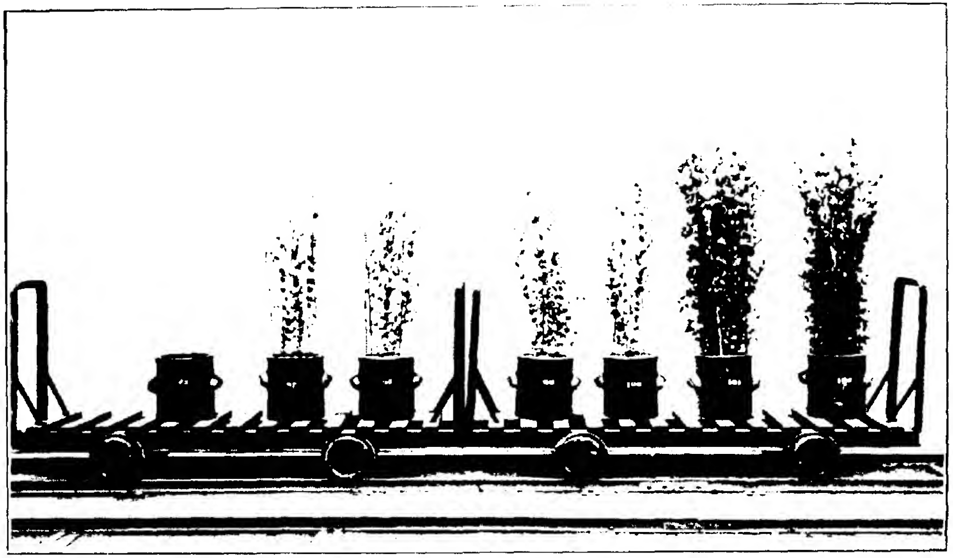


PLATE X.



PEAS, 1908-9.

97, 98. No manure.
99, 100. Nitrate only.
101, 102. Nitrate and superphosphate.

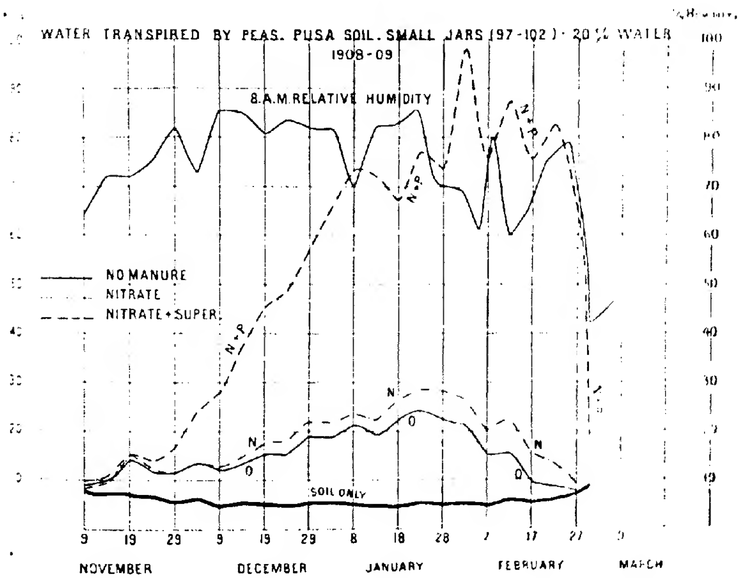
STATEMENT X.

PISUM SAT. (PEAS) 1908-09.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
x	A = 9" diam. × 12" deep.	About 14 kilos of Pusa soil.	20		Blank jars		...	..	(6·00)	..
97			20	Nil ...	2-11-08	1-3-09	5·5	11·6	11·29	973
98			20		2-11-08	1-3-09	7·2	15·8	11·03	698
99			20	N ...	2-11-08	1-3-09	8·5	20·1	14·94	743
100			20		2-11-08	1-3-09	6·8	16·6	13·71	826
101			20	N+P ...	2-11-08	3-3-09	47·9	115·7	52·35	453
102			20		2-11-08	3-3-09	36·2	94·9	57·72	608

N = $Ca(NO_3)_2$ = ·005 grm. N; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART X.



STATEMENT XI.

Cicer arietinum (Gram) 1908-09.

Jar No.	Jar size.	Soil per jar.	Water in soil, Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	[illegible]
×	A = 9" diam. × 12" deep.	About 14 kilos of Pusa soil.	20		Blank jars		...	...	(7·09)	
103			20	Nil	2-11-08	8-3-09	2·4	7·0	10·66	1523
104			20	Nil	2-11-08	8-3-09	3·7	8·9	11·88	1335
105			20	N	2-11-08	8-3-09	4·7	9·9	10·40	1050
106			20	N	2-11-08	8-3-09	3·8	10·2	13·49	1323
107			20	N + P	2-11-08	8-3-09	7·2	21·1	23·78	1127
108			20	N + P	2-11-08	8-3-09	30·7	67·1	55·36	825

N = $Ca(NO_3)_2$ = ·005 grm. N; P = superphosphate = ·01 grm. soluble P_2O_5 per [illegible] grms. soil.

CHART XI.

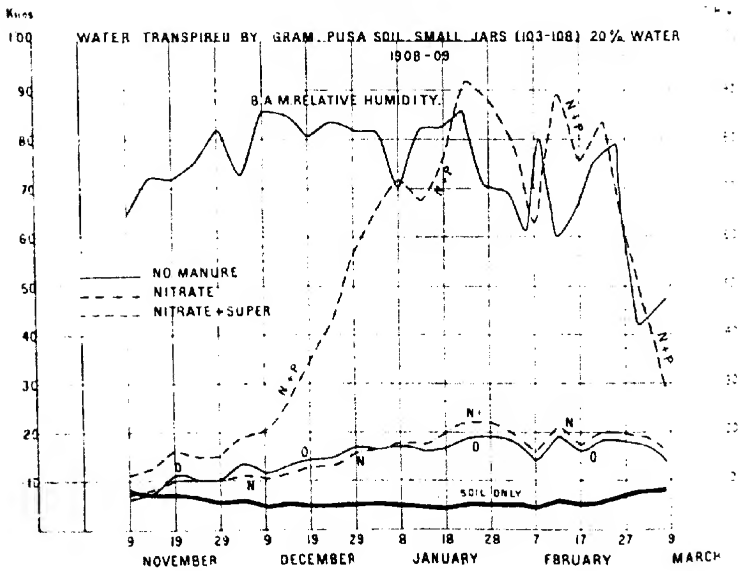
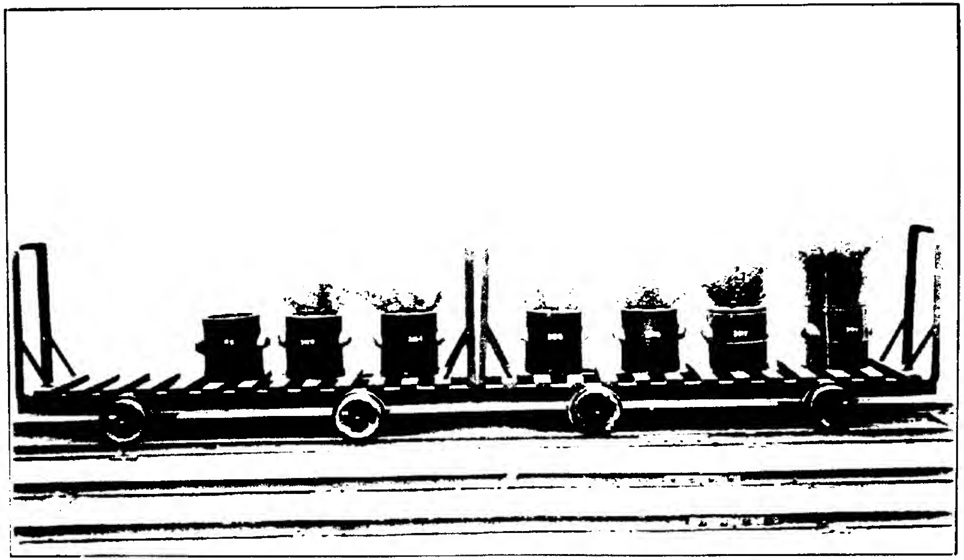


PLATE XI.



GRAM, 1889.

103, 104. No manure.
105, 106. Nitrate only.
107, 108. Nitrate and Superphosphate.

STATEMENT XII.

Zea mais (Maize) 1907.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
1	A = 9" diam. × 12" deep.	About 15 kilos of Pusa soil.	10	Nil	21·7·07	20·10·07	·05	11·26	5·17	459
2			10	N	21·7·07	20·10·07	Nil	20·07	8·11	404
3			10	N + P	21·7·07	20·10·07	Nil	41·41	11·90	287
4			10	N + P + K	21·7·07	20·10·07	Nil	41·23	14·21	344
5			10	Nil	Blank	jar			(2·27)	
6			15	Nil	21·7·07	20·10·07	·1	11·63	4·28	368
7			15	N	21·7·07	20·10·07	·15	28·53	10·78	377
8			15	N + P	21·7·07	20·10·07	4·9	35·10	11·31	323
9			15	N + P + K	21·7·07	20·10·07	·7	24·12	7·79	322
10			15	N + P + K	Blank	jar			(3·65)	
11			20	Nil	21·7·07	20·10·07	Nil	11·26	6·81	604
12			20	N	21·7·07	20·10·07	Nil	17·1	9·05	529
13			20	N + P	21·7·07	20·10·07	1·8	35·82	13·70	382
14			20	N + P + K	21·7·07	20·10·07	·2	51·03	17·15	336
15			20	Nil	Blank	jar	...	...	(3·73)	...

N = Ca $(NO_3)_2$ = ·005 grm. N per 100 grms. soil P = superphosphate = ·010 grm. soluble P_2O_5 and K = K_2SO_4 = ·005 grm. K_2O per 100 grms. soil.

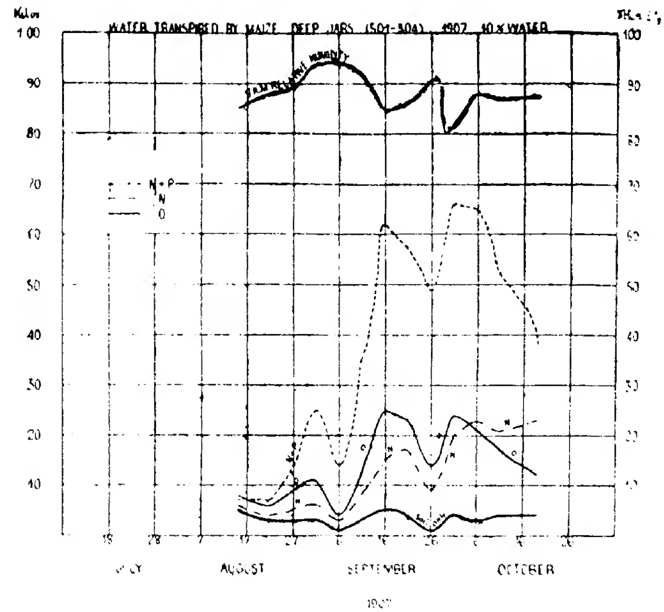
Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
401	B = 9" diam. × 16" deep.	About 21 kilos of Pusa soil.	10	Nil	20·7·07	20·10·07	·40	13·0	6·52	500
402			10	N	20·7·07	20·10·07	·40	16·85	10·87	645
403			10	N + P	20·7·07	20·10·07	18·60	67·8	20·98	309
404			10	Nil	Blank				(4·21)	
405			15	Nil	20·7·07	20·10·07	Nil	10·22	6·02	589
406			15	N + P	20·7·07	20·10·07	22·00	92·07	25·86	281
407			15	N + P	Blank				(7·51)	
408			20	Nil	20·7·07	20·10·07	1·30	15·4	5·88	381
409			20	N	20·7·07	20·10·07	1·80	21·0	11·16	527
410			20	N + P	20·7·07	20·10·07	5·70	82·7	24·41	295
411			20	Nil	Blank				(9·70)	...

N = Ca $(NO_3)_2$ = ·005 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
501	C = 9" diam. × 20" deep.	About 31 kilos of Pusa soil.	10	Nil	20·7·07	19·10·07	Nil	16·8	7·56	450
502			10	N	20·7·07	19·10·07	Nil	15·4	6·35	412
503			10	N + P	20·7·07	19·10·07	17·8	92·2	24·16	262
504			10	Nil	Blank	jar			(3·02)	
505			15	Nil	20·7·07	19·10·07	4·8	26·25	11·06	421
506			15	N	20·7·07	19·10·07	2·2	29·07	11·68	505
507			15	N + P	20·7·07	19·10·07	18·5	97·80	27·97	286
508			15	N + P	Blank	jar			(5·73)	
509			20	Nil	20·7·07	19·10·07	1·1	30·75	13·20	429
510			20	N	20·7·07	19·10·07	1·8	34·03	18·73	480
511			20	N + P	20·7·07	19·10·07	4·7	112·08	33·33	295
512			20	Nil	Blank	jar			(9·16)	

N = Ca $(NO_3)_2$ = ·005 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART XIIa.


WATER TRANSPIRED BY MAIZE DEEP JARS (501-504) 1907 40 X WATER
Kilos
100
90
80
70
60
50
40
30
20
10
N+P
N
O
AUGUST
SEPTEMBER
OCTOBER

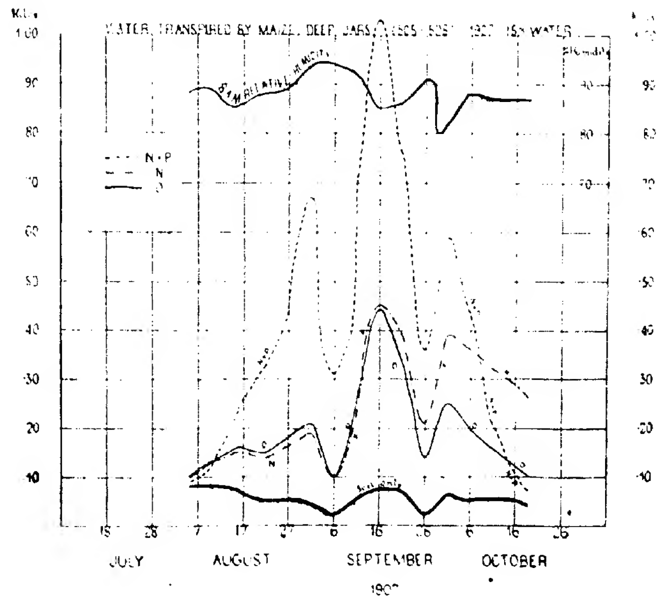
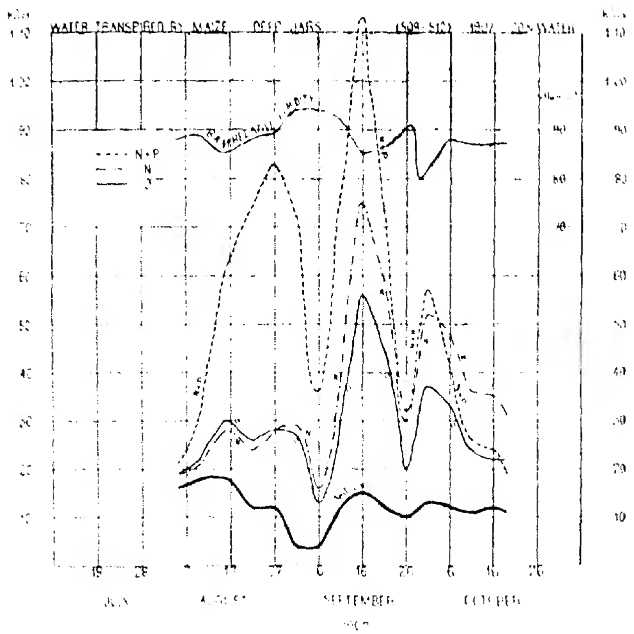

WATER TRANSPIRED BY MAIZE, DEEP JARS
Kilos
100
90
80
70
60
50
40
30
20
10
N+P
N
O
15
28
7
17
27
6
16
26
6
16
26
JULY
AUGUST
SEPTEMBER
OCTOBER

CHART XIIA.



STATEMENT XIII.

ZEA MAIS (MAIZE) 1908.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
[illegible]	A = 9" diam. × 12" deep.	About 14 kilos of Pusa soil.	20	...	Blank jars			...	(7·80)	
2			20	Nil	8-6-08	17-9-08	Nil ...	31·4	14·02	446
3			20		8-6-08	17-9-08	Nil ...	31·5	12·51	397
4			20	N ...	8-6-08	17-9-08	Nil ...	30·4	14·58	480
5			20		8-6-08	17-9-08	·2	32·8	13·01	397
6			20	N : P ...	8-6-08	17-9-08	Nil ...	49·9	22·41	444
7			20		8-7-08	17-9-08	·5	65·0	27·41	422

N = $Ca(NO_3)_2$ = ·005 grm. N; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART XIII.

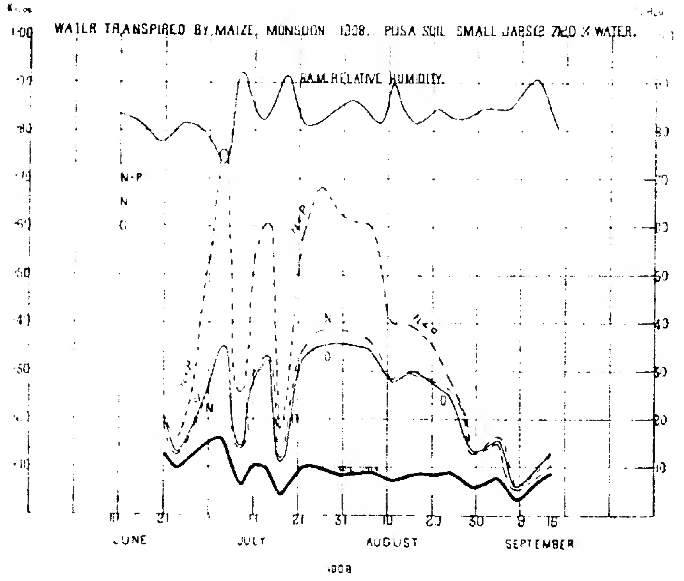
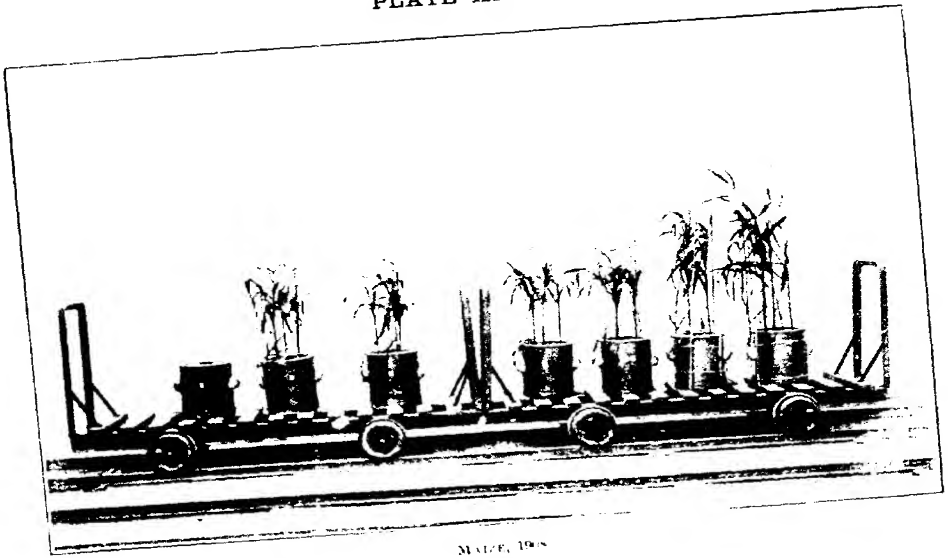


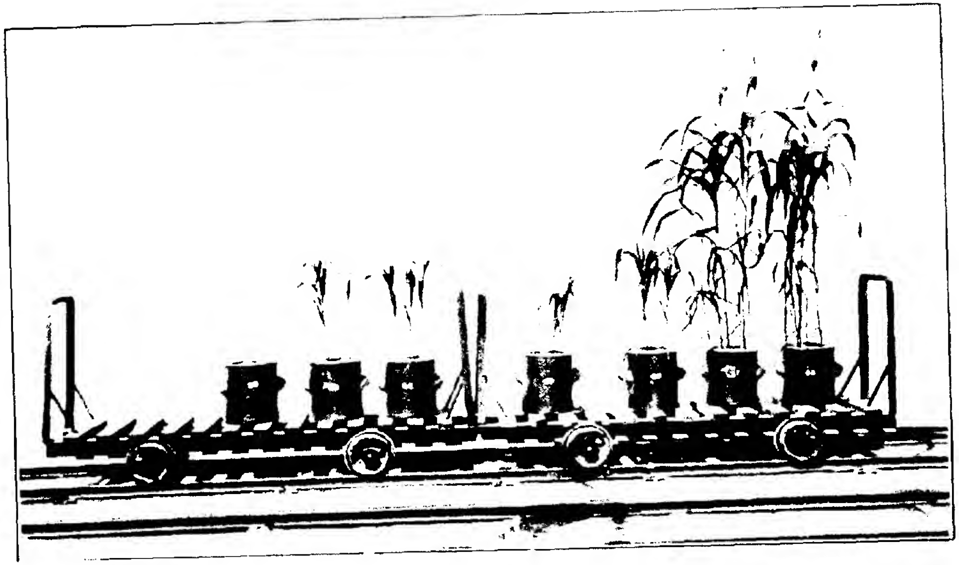
PLATE XIII.



MAIZE, 19[illegible]

2, 3. No manure.
4, 5. Nitrate only.
6, 7. Nitrate and Superphosphate.

PLATE XIV.



JUNE, 1908.

43, 44. No manure.
45, 46. Nitrate only.
47, 48. Nitrate and superphosphate.

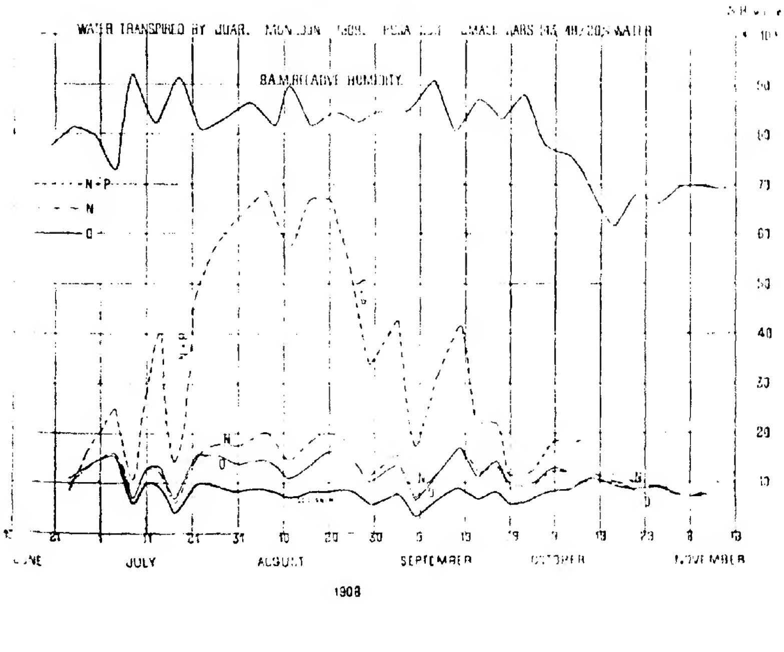
STATEMENT XIV.

ANDROPOGON SORGHUM (JUAR) 1908.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
[illegible]	A = 9" diam. × 12" deep.	About 14 kilos of Pusa soil.	20	..	Blank	jars			(11·94)	
43			20	Nil	15·6·08	13·11·08	2·1	12·6	3·40	270
44			20	Nil	15·6·08	13·11·08	2·4	14·8	6·67	451
45			20	N	15·6·08	13·11·08	1·4	12·7	6·21	489
46			20	N	15·6·08	13·11·08	1·8	20·3	7·11	350
47			20	N + P	15·6·08	16·10·08	5·4	74·3	36·19	486
48			20	N + P	15·6·08	16·10·08	9·1	72·5	28·10	388

N = $Ca(NO_3)_2$ = ·005 grm. N ; P = superphosphate ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART XIV.



STATEMENT XV.

ORYZA SATIVA (RICE) 1908.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
×	A — 9" diam. 12" deep.	About 14 kilos of Pusa soil.	20	...	Blank jars		...	...	(15·00)	
23			20	Nil	10-6-08	18-12-08	5·4	17·8	20·15	1132
24			20	Nil	10-6-08	18-12-08	4·8	22·5	18·45	820
25			20	N	10-6-08	18-12-08	6·9	23·7	25·24	1065
26			20	N	10-6-08	18-12-08	3·6	24·7	20·62	835
27			20	N + P	10-6-08	18-12-08	13·5	43·1	35·48	823
28			20	N + P	10-6-08	18-12-08	16·6	62·2	49·64	798

N = $Ca(NO_3)_2$ = ·005 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART XV.

WATER TRANSPIRED BY RICE MONSOON 1908 PUSA SOIL SMALL JARS (23-28) 20% WATER

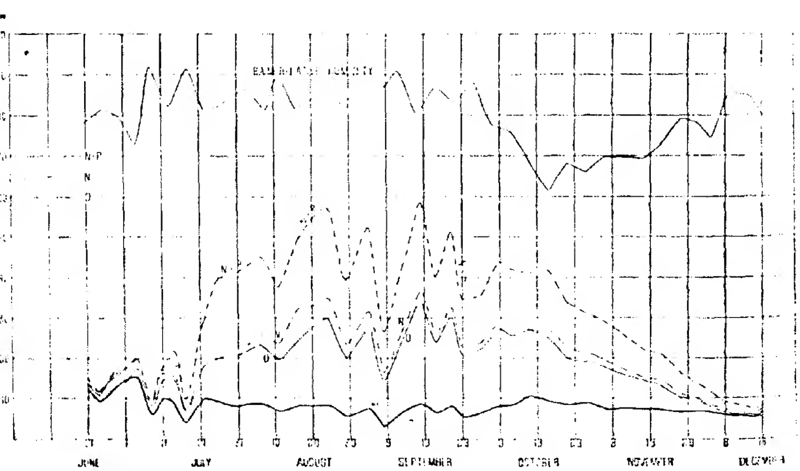
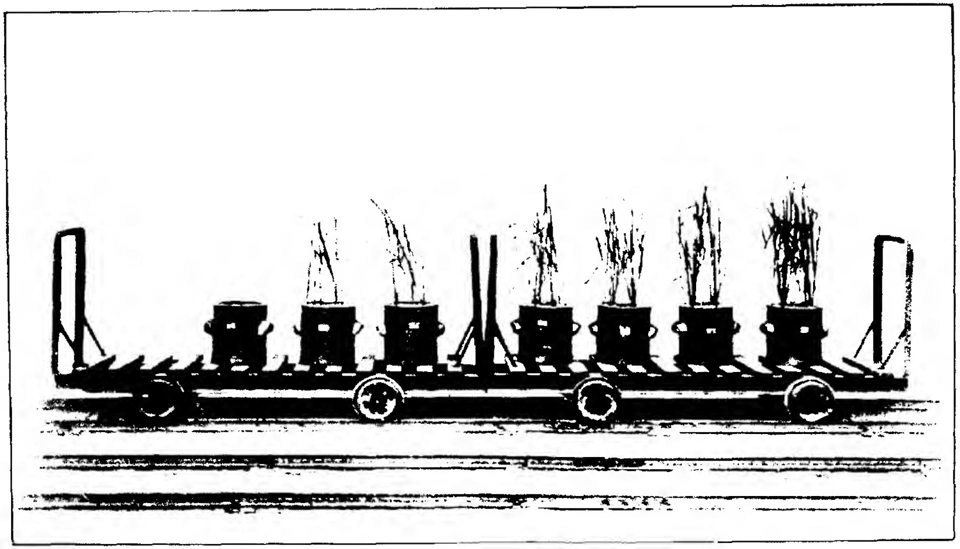


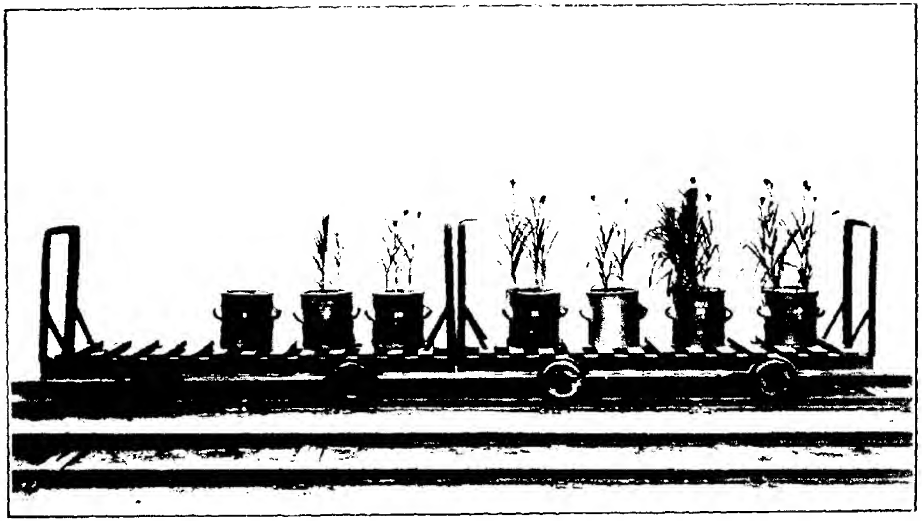
PLATE XV.



Rice, 1908.

23, 24. No manure.
25, 26. Nitrate only.
27, 28. Nitrate and Superphosphate.

PLATE XVI.



MURWA, 1908.

9, 10. No manure.
11, 12. Nitrate only.
13, 14. Nitrate and Superphosphate.

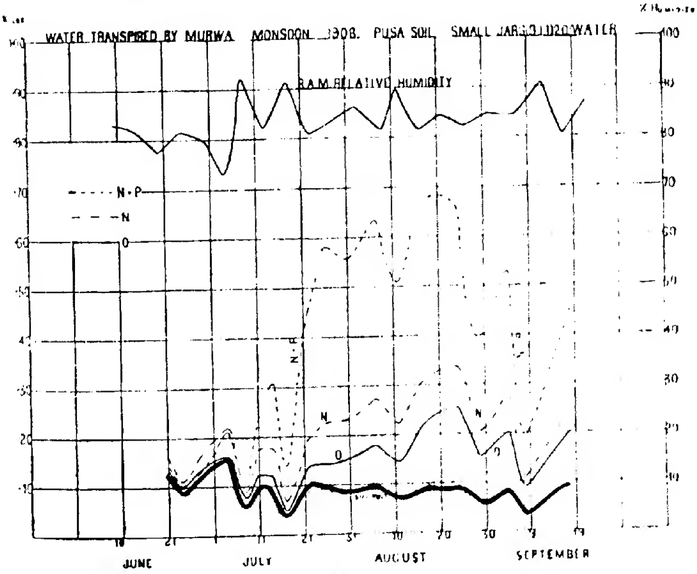
STATEMENT XVI.

Elecusine coracana (Murwa, ragi) 1908.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
x	1 ×	About 14 kilos of Pusa soil.	20		Blank jars				(7·99)	
9	A = 9" diam. × 12" deep.		20	Nil	9·6·08	19·9·08	4·2	25·0	5·11	204
10			20		9·6·08	19·9·08	1·2	26·6	8·08	304
11			20	N	9·6·08	19·9·08	7·2	49·4	15·33	310
12			20		9·6·08	19·9·08	4·5	33·2	8·50	256
13			20	N + P ..	9·6·08	19·9·08	22·6	133·3	35·37	265
14			20		9·6·08	19·9·08	22·1	89·1	23·26	261

N = Ca $(NO_3)_2$ = 0·05 gm. N ; P = superphosphate 0·1 gm. soluble P_2O_5, per 100 grms. soil.

CHART XVI.



STATEMENT XVII.

PASPALUM SCROBICULATUM (KODO) 1908.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
... x	A = 9" diam., 12" deep.	About 14 kilos of Pusa soil.	20	...	Blank jars				(9·74)	
16			20	Nil	10-6-08	13-10-08	8·9	19·5	6·37	326
17			20		10-6-08	13-10-08	7·9	17·0	8·58	336
18			20	N	10-6-08	13-10-08	8·3	22·0	5·71	259
19			20		10-6-08	13-10-08	10·3	23·8	6·50	273
20			20	N + P	10-6-08	13-10-08	35·5	74·2	23·47	316
21			20		10-6-08	13-10-08	19·2	43·7	13·44	[illegible]

N = Ca $(NO_3)_2$ = ·005 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART XVII.

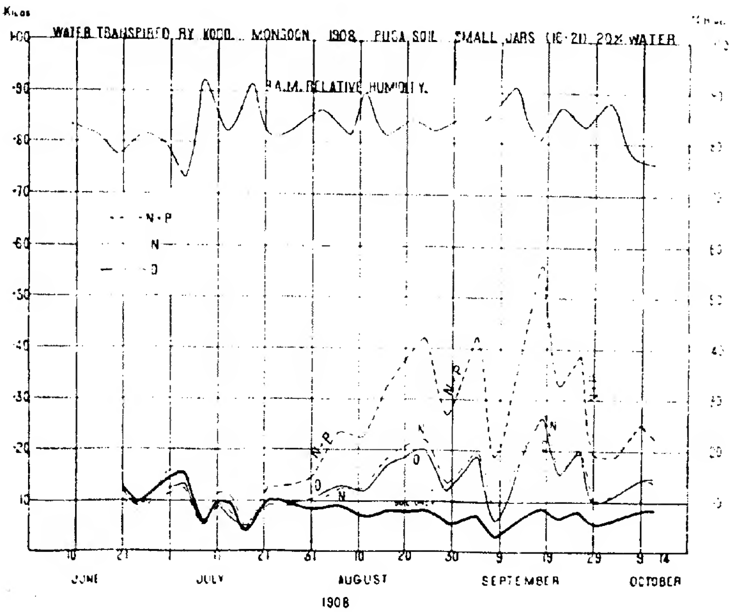
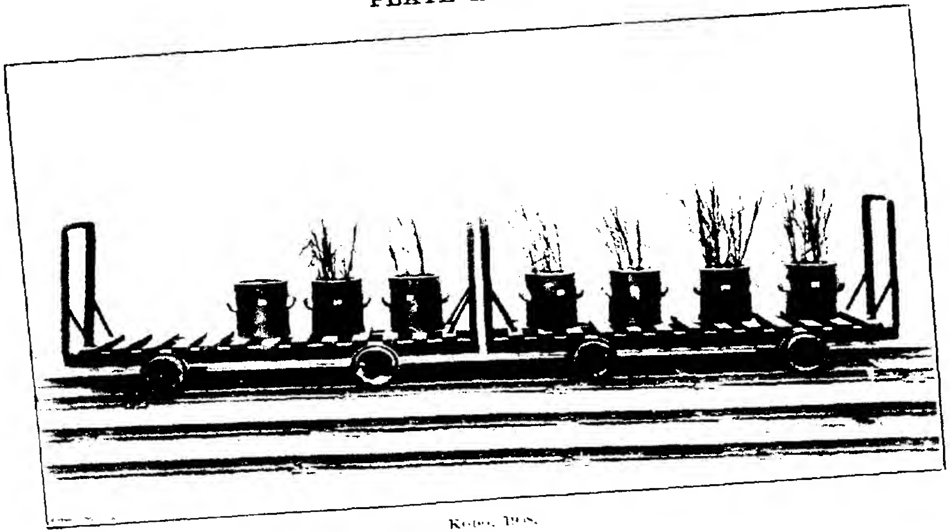


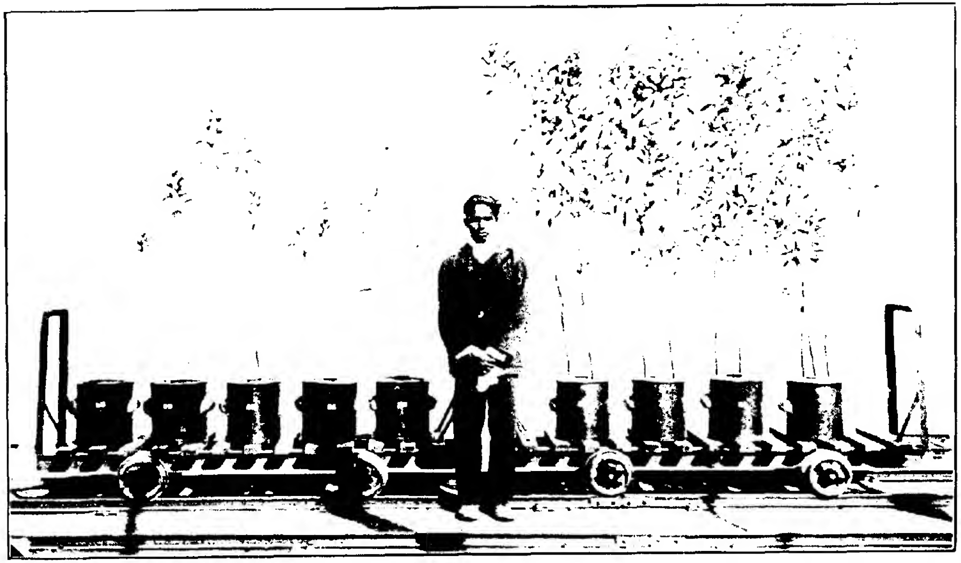
PLATE XVII.



Kotes, 1908.

16, 17. No manure.
18, 19. Nitrate only.
20, 21. Nitrate and Superphosphate.

PLATE XVIII.



ARHAR, 1908-9.

29, 30. No manure.
31, 32. Nitrate only.
33, 34. Nitrate and Superphosphate.
35, 36. Nitrate, Phosphate and Potash.

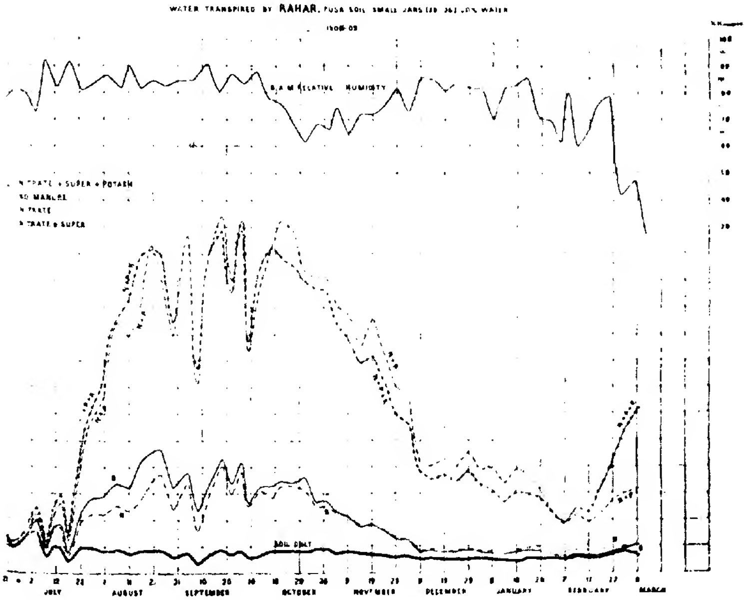
STATEMENT XVIII.

Cajanus Indicus (Rahar) 1908-1909.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
	A"–9" diam. 12" deep.	About 14 kilos of Pusa soil.	20		Blank jars				(19·00)	
29			20	Nil ...	11·6·08	10·3·09	2·4	22·2	26·79	1207
30			20		11·6·08	10·3·09	3·5	40·3	40·74	1011
31			20	N	11·6·08	10·3·09	2·4	22·2	24·93	1123
32			20		11·6·08	10·3·09	2·1	24·8	33·91	1367
33			20	N + P ...	11·6·08	10·3·09	33·9	250·4	169·30	676
34			20		11·6·08	10·3·09	35·8	236·2	142·52	603
35			20	N + P + K	11·6·08	10·3·09	28·5	230·2	150·80	655
36			20		11·6·08	10·3·09	29·4	265·2	160·47	605

N = $Ca(NO_3)_2$ = ·005 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 ; K_2SO_4 = ·005 grm K_2O per 100 grms. soil.

CHART XVIII.



STATEMENT XIX.

Cyamopsis psoralioides (Guar) 1908.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
×	A 9" diam. × 12" deep.	About 14 kilos of Pusa soil.	20	......	Blank jars		...	...		
37			20	Nil ...	11-6-08	3-12-08	7·3	24·7	27·15	1099
38			20		11-6-08	3-12-08	5·2	16·3	17·35	1064
39			20	N ...	11-6-08	3-12-08	3·7	10·9	9·68	888
40			20		11-6-08	3-12-08	4·5	12·9	15·62	1211
41			20	N + P ...	11-6-08	3-12-08	53·2	153·2	90·48	591
42			20		11-6-08	3-12-08	45·7	121·9	73·59	604

N = $Ca(NO_3)_2$ = ·005 grms. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART XIX.

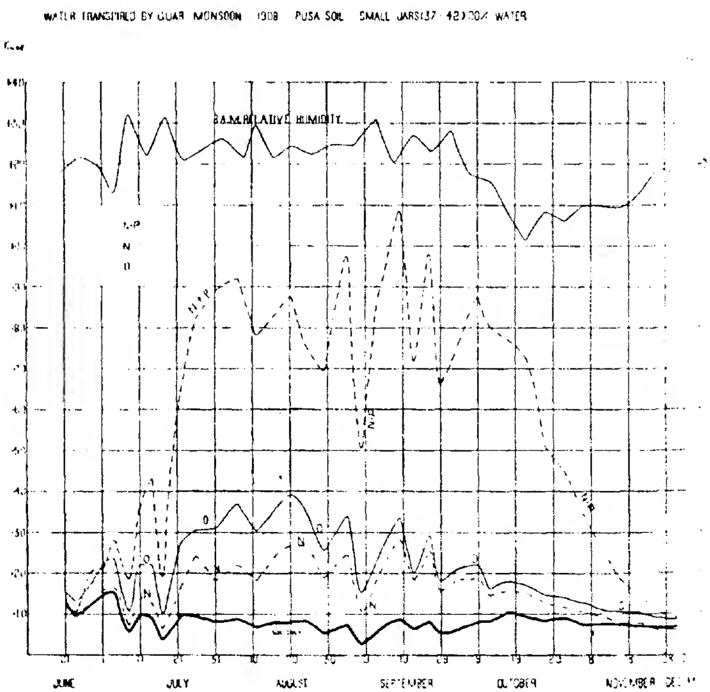
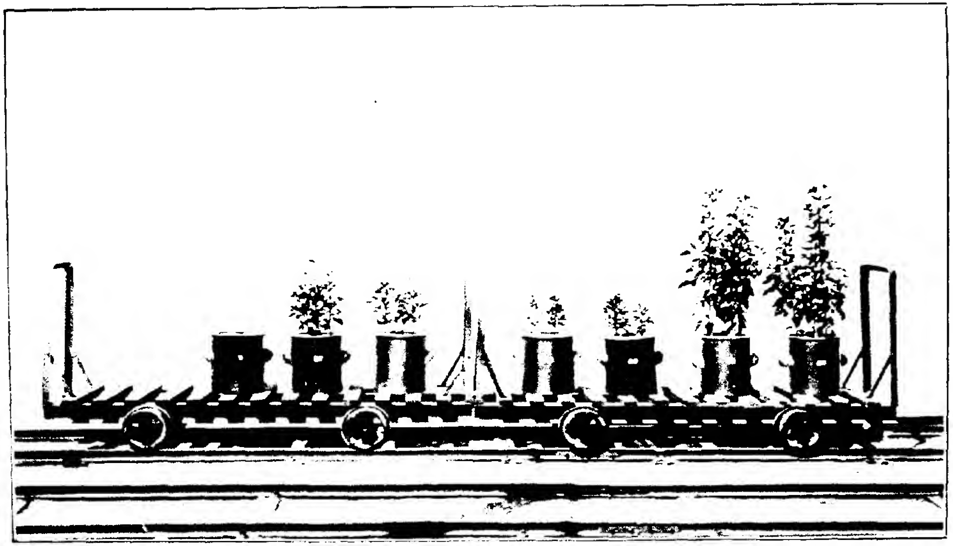


PLATE XIX.



[illegible]

7, 38. No nitrate [illegible]

39, 40. N[illegible]

41, 42. N[illegible]

PART III.

DEDUCTIONS.

The effect of different sized jars.—Cultivation jars of different size have only been used for two of the crops, namely, wheat and maize, but this has been done during several seasons. One may anticipate therefore that any appreciable effect which this factor is liable to exert will be brought out in the series. For a complete comparison reference must be made to the statements, but it will be sufficient if the ratios obtained by the use of large and small jars of soil, unmanured, and manured with nitrate and phosphate or oil-cake and phosphate, and containing a high proportion of water, are here set out.

STATEMENT XX.

Crop.	Soil.		Manured.		Unmanured.	
			Small Jars.	Large Jars.	Small Jars.	Large Jars.
			Ratio.	Ratio.	Ratio.	Ratio.
Wheat ...	Pusa ...	1906-7	574	515	829	955
,, ...	,,	1907-8	725	605	1,133	821
Maize ..	,,	1907	382	295	604	429

This comparison shows that almost uniformly a lower ratio is obtained by the use of large jars, that is, a large mass of earth, and the same has been found quite as uniformly in other experiments. On the whole, the experience gained indicates that the use of large jars containing about 50 kilos of soil offers distinct advantages; some plants such as maize and juar develop much more perfectly in these than in jars holding only about one-fourth the weight of soil. The effect on the ratio may be stated to be quite 10 to 20 per cent.

The effect of the proportion of water in the soil.—The experiments of the two cold weather seasons 1906-07, 1907-08 and the monsoon 1907, included soil containing materially different proportions of water. Attention has already (page 142) been directed to the fact that it is not possible to maintain a *constant*

proportion of water in the soil in pot-cultures and that indeed the amount of water transpired by vigorous plants growing in small jars occasions a very considerable diurnal variation. Among the advantages attending the use of the large jars is the maintenance of a more uniform proportion of water in the soil. We may however compare some of the ratios obtained from plants growing in soil with certain "nominally fixed" proportions of water, for if this factor controls the ratio in an important degree, it should become evident where the differences in the proportion of water are as great as those adopted.

STATEMENT XXI.

Crop.	Soil.	Manure.	Percentage of water in soil.		
			10	15	20
			Ratio.	Ratio.	Ratio.
Wheat	Pusa	Nil.	900	653	829
		"	941	1,060	955
		"	634	.	1,133
		"	696		821
		Manured.	543	540	574
		"	593	504	515
		"	571	...	725
		"	446		505
Maize ...	"	No manure.	459	368	604
		Manured.	289	323	382
		Nil.	500	589	381
		Manured.	309	281	295
		Nil.	450	421	429
		Manured.	262	286	295

Of these it cannot be said that the ratio is generally, and still less uniformly, affected by the amount of water in the soil. There is on the whole a larger number of cases in which it is higher with the moister soil than the reverse. On the other hand, the development of "unmanured" plants has been very imperfect in many cases and the ratios consequently somewhat less reliable. On the whole, there is nothing in the evidence to show that the ratio is affected by this factor in so far as these experiments go. At the same time they are distinctly limited: only one soil was employed and the lowest proportion of water employed was 10 per cent. Whether the *ratio* would be affected

by lower proportions of water in this soil, and in how far it would be affected in other soils, one cannot say. As a matter of fact, we are here broaching an entirely different subject, namely, in how far water is "available" to plants in different soils. Hellriegel* made experiments on the subject in 1872 and following years, but it is far from being perfectly understood. Similarly in regard to a high proportion of water we are largely ignorant of what its effect on crops is. Hellriegel's experiments showed that a maximum development was achieved when the soil contained between 30 and 60 per cent. of that amount of water which would "saturate" the soil. Unfortunately the determination of this "saturating" proportion is not simple or accurate, and it becomes correspondingly difficult to decide what either 30 per cent. or 60 per cent. of this is.

So far as India is concerned, our chief object is naturally the determination of the *smallest*, and not the largest, amount of water which should be in a soil, and the upper limit is only of importance in cases of waterlogging.

The effect of manure.—By far the most marked feature of the experiments is the effect of manure on the ratio. Confining attention for the moment to a comparison between the produce of unmanured soil and that manured with nitrate plus phosphate, a glance at the statements shows that the ratio for wheat is only about $\frac{2}{3}$ in the latter case to what it is in the former. The effect on the ratio for maize is often equally great though this is not uniformly the case. The ratios of rahar, guar, barley, oats, gram and peas were all similarly affected; the ratios for the remaining crops were decreased in the cases of manured soil, although not affected to a like degree.

As to the characteristic in the manure which is the chief agent in reducing the ratio, the majority of the data are apt perhaps to give the impression that the superphosphate has played this part. But experiments in another soil negatived this conclusion. It was a soil selected in part because the amount of

* For a complete account of Hellriegel's experiments see Hellriegel's Beitz. zu d. wiss. Grundlagen d. Ackerbaues, pp. 525—598

phosphate in it, as shown by Dyer's and other tests, was high, and it was anticipated that superphosphate would not increase the outturn; an expectation which was realised. In it the best crop was obtained by the use of nitrate only, and here also the transpiration ratio was lowest. The effect of manure depends on the soil. If there is a serious deficiency of phosphate, nitrate will not increase the crop or decrease the ratio as would a mixture of nitrate and superphosphate. As regards potash, the use of sulphate of potash in the manures has in no case markedly increased the outturn, and accordingly the data do not show any change in the value of the ratio as due to this fertilizer. Speaking generally, *the effect of a suitable manure in aiding the plant to economise water* is the most important factor which has been noticed in relation to transpiration.

But one may go further than this. A comparison of the ratios obtained from duplicate jars of manured soil reveals the fact that, whenever the plants of one of the pairs of jars developed more perfectly than the other, the better development has been accompanied by a lower ratio. The magnitude of the effect has varied, but the uniformity of the result is such as to leave no doubt of the fact. The conclusion may hence be drawn that *not only manure, but good tillage, a deep soil and indeed any factor which aids in good development of the crop will tend towards an economy of water.* It presumably also explains why the ratios obtained with large jars of soil are usually distinctly smaller than with small jars, the larger quantity of soil causing a better development of plant and a consequently reduced ratio. We may properly bear this fact in mind when considering the quantities of water required by crops. Those set out on page 178 are deduced from the ratios obtained mostly in small jars of soil, and consequently the calculated quantities of water are probably rather high.

The effect of length of period of growth.—At one stage of the experiments it seemed that the length of the period between seed-time and harvest exerted a material influence on the transpiration ratios; that indeed this increased with the length of the period.

In the following statement are set out the ratios and the length of growing period for all the crops which have been grown without respect of season.

STATEMENT XXII.

	Period, Days.	Transpiration Ratio, No Manure.	Transpiration Ratio, Manured.
Maize	90	450	330
Murwa ...	100	250	250
Kodo	120	300	300
Sarson	120	740	620
Barley	120	680	480
Oats	120	870	550
Peas	120	830	530
Gram	120	1,400	1,000
Linseed	120	1,000	1,000
Wheat ..	150	850	550
Juar ..	150	400	400
Guar	170	1,100	600
Rice	180	1,000	800
Rahar ..	240	1,100	600

A glance over these ratios shows that in a *general* way those crops which mature rapidly have a low ratio, and the longer lived ones a high ratio; but there are several conspicuous exceptions. Linseed and gram have much higher ratios than oats, barley, peas or sarson, all of which have the same length of growing period at the same time of the year. The linseed ratio may be somewhat high, but the plant developed very well, especially that grown in manured soil, and there seems no reason to doubt that its ratio is actually much higher than the others named. A similar remark applies to the gram. The difference between the ratios for wheat and juar, which require about equal lengths of time for maturity, may reasonably be ascribed to difference of season, because the wheat is grown during the cold weather when, the temperature is comparatively low and the humidity also low, whilst the juar enjoys the monsoon period for the greater part of the time it occupies the land, when both the temperature and humidity are a good deal higher.

The third conspicuous exception is provided by rahar (cajanus Indicus) which enjoys a total growing period very considerably longer than any of the other crops named, and has a ratio, high it is true, but not at all in proportion to its length of growth.

The general conclusion then seems to be that the length of growing period exerts either no influence on the ratio or at least only a modified one.

The nature of the crop.—The question may likewise be asked whether the nature of the crop is a factor of importance. But then what is one to understand by the term "nature of the crop?" If it is interpreted as a botanical classification, then one must conclude that there is little or no connection between the natural order and the ratio. At the same time the exceptions which have been dealt with in the last paragraph tend to indicate that for each plant there is a specific ratio, which of course will be modified by the various factors surrounding the plant. In the absence of a better explanation, this seems to be the only legitimate one to offer for the markedly different ratios which have been met with. One would then lay down as a general principle that for each plant there is a specific ratio, the magnitude of which is controlled by various circumstances, and hence that the ratio for a certain crop which has not been tested, can only be prognosticated within certain wide limits.

The effect of temperature and humidity.—Experiments have frequently been made to ascertain the effect of temperature and humidity on transpiration, and the results have shown that the amount of water transpired per unit of time is increased by a rise of temperature and decreased by a rise of humidity in the air. For a more detailed account of such experiments the reader may consult "Hellriegel's Grundlagen des Ackerbaus," pp. 456 to 700, and "Burgerstein's Die Transpiration der Pflanzen," pp. 115-128. The result might indeed be anticipated on both physiological and physical grounds, for with a rise of temperature (within certain limits) the plant's energy is increased, and a rise of temperature would cause from unit surface an increased evaporation; similarly a decreased relative humidity would aid evaporation. The experiments referred to have been, however, mostly made on plants in this connection for only short periods, whilst for our purposes the effect of the season *as a whole* is required. That humidity influences transpiration is readily shown by the daily

records; on a wet day the quantity of water transpired decreases to say one-quarter or one-fifth of what it is on a fine day. An examination of the charts which have been reproduced in this memoir also shows it very well, for with every serious increase in humidity there is either a check in the direction of the transpiration curve or a dip in it Frequently, more especially during the initial period of growth, the daily increase in the plant's energy is so great that the effect of an increased humidity is insufficient to *decrease* the transpiration and merely checks the daily increase: but during the later periods the amount of water transpired during wet weather falls to a very small figure. During *continuously* wet weather the protracted suspension of transpiration doubtless accounts for the yellowing of crops.

But although the effect of increased humidity on the daily transpiration is so marked, it remains to be ascertained whether the variation between one season and another is sufficient to cause a measurable difference in the total water transpired, and secondly, whether this will chiefly cause a difference in the weight of crop, or chiefly affect the transpiration ratio?

Hellriegel sets out (pp. 664–72) a comparative analysis of temperature and humidity during three seasons at Dhame in relation to the mean transpiration ratio for barley obtained from a whole growing period: this was 366 in a relatively warm and dry year, 1868, whereas it was 263 in a cooler and damper year, 1870. The chief data may be suitably quoted.

STATEMENT XXIII.

Year.	Mean temperature.	Mean humidity.	Ratio.
1868	66	65·7	366
1870	64	71	263

The difference in mean temperature is so slight that to it can hardly be attributed any large part of the difference in the quoted ratios. The chief cause of doubt that may be legitimately entertained of the soundness of his deduction, is that these ratios are in each case the arithmetical mean of a number

of ratios which varied among themselves to as great an extent as the two quoted.

The subject is best considered under two distinct sub-heads. The first relates to the difference of *plant*, the second to the difference of *season*.

As to the *plant*, reasons have already been advanced for assuming that each has probably its particular transpiration ratio. This feature of its development will no doubt be in part if not largely the outcome of its climatic surroundings, not of any one season in particular but of the many during which it has been gradually produced and to which it has become accustomed. Our monsoon crops, for instance, have enjoyed for generations a humid atmosphere, the cold-weather ones a relatively dry one. In this probably lies the explanation why the ratio of the monsoon crops is often so much below those of the cold weather.

In respect of difference of *season* it is difficult, without very considerable experience coupled with a sufficiency of suitable data, to ascertain their effect, and this is well illustrated by the following extracts from our records.

Chart No. XXIV(*a*) shows the 8 A.M. relative humidity in the upper part, and the "mean day temperature" in the lower, for the three cold weather seasons 1906-07, 1907-08, 1908-09. Chart No. XXIV(*b*) gives similar information for the two monsoon periods, 1907, 1908. Regarding the humidity, it must be admitted that the 8 o'clock record is not altogether suitable for our purpose because the relative humidity falls generally so very much as the temperature rises during the day, but an average figure is not available, and the humidity at 8 o'clock is the only record to judge by. The "mean day temperature" is the arithmetical mean between the 8 o'clock and maximum temperature. Since it is known that the greater part of the transpiration occurs during the day time, this mean figure seemed to offer a better basis of comparison than, the mean temperature of the 24 hours.

An inspection of chart No. XXIV(*a*) shows that the humidity was generally higher in the season 1906-07, than in

CHART XXIVa.

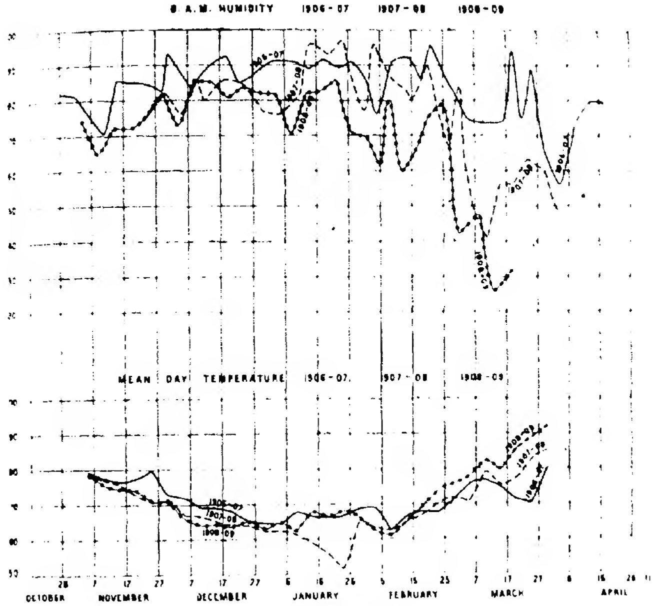
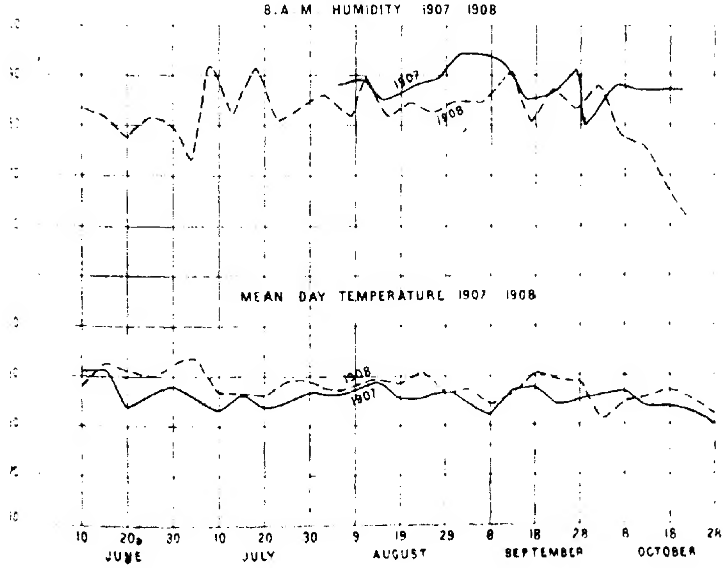


CHART XXIVb.



1907-08 and this again generally higher than in 1908-09: the temperatures of the three seasons were practically alike except for the cold period in January 1908 which cannot be considered likely to affect the total transpiration. If such differences in season affect the general transpiration seriously, it should have been lower in 1906-07 than in 1907-08 and highest in 1908-09. A similar examination of chart No. XXIV(*b*) shows that the monsoon of 1907 was cooler and damper than that of 1908 and the transpiration should therefore have been higher in the latter. Then will come the question as to whether the effect will be a generally increased growth or a higher transpiration ratio. As to the former there are no data: the experiments were not designed for the purpose, and there are so many factors influencing gross outturn in pot-cultures, that it is doubtful in how far these are in this respect comparable between one season and another. The effect on the *ratio* might, however, be perceptible. The data which are comparable are set out in statement No. XXIV. The ratios quoted in this are, in most cases, the means of those obtained in the experiments when the conditions were alike except for the amount of water present in the soil, which is considered to have no influence on the ratio.

STATEMENT XXIV.

	Year.	Jar size.	Manure.	Ratio.
Wheat	1906-07	A	Nil	794
		B	..	985
	1907-08	A	..	883
		C	..	758
	1908-09	A	..	865
Wheat	1906-07	A	Complete	547
		B	..	558
	1907-08	A	..	648
		C	..	476
	1908-09	A	..	507
Maize	1907	A	Nil	477
		B	..	490
		C	..	433
	1908	A	..	421
Maize	1907	A	Complete	332
		B	..	295
		C	..	281
	1908	A	..	433

An inspection of these data shows that the ratio for wheat was certainly not perceptibly influenced by the season, and the same remark applies to the maize grown in unmanured soil; the ratio for maize grown in manured soil was certainly lower in the cooler and damper season 1907 than in 1908. The divergence is marked, even if those for the same size of jar only are compared. Even if there had been no other evidence, too much weight would not be applicable to the ratio 433 for 1908: it is the mean of two closely coinciding ratios, but on the other hand the maize did not grow well in these small jars. There were, however, data obtained in 1908 from other experiments, to be quoted on a subsequent occasion, and if these were brought into the comparison, a somewhat lower ratio would be obtained for the 1908 season. This special reference to maize grown in manured soil is not made with the object of proving that sometimes the season affects the ratio, but rather to show how difficult it is to make a really definite deduction on this subject with the aid of only two or three seasons. Then, again, it is to be recollected that the plant itself possesses organs, such as the stomata, wax deposit, hairy growth, etc., which enable it to control transpiration.

The differences of season during the last three years have been relatively very large: the cold weather of 1906-07 was unusually wet and cool and that of 1908-09 unusually dry; there were nearly as great differences in the two monsoons; and since it has been so difficult to perceive an effect on the transpiration ratio obtained during these periods, it is legitimate to conclude that the effect of variation of season on the transpiration ratio is not large, probably not 10 per cent., but it is equally certain that one cannot make reliable deductions regarding the ratio for other parts of India. Perhaps, it would be reasonable to conclude that the ratios obtained at Pusa will be within 25 per cent. of the truth for any other part of India, in so far as climate is concerned.

The diurnal change in transpiration.—A decreased transpiration during the night period has been noticed by a number of

vegetable physiologists. A couple of extracts from our records are of interest since no others exist for India.

STATEMENT XXV.

Date.	Period.		Temperature.		Humidity.	Water lost—Kilograms.				
		Hours.	Max.	Min.	8 a.m.	Maize.	Murwa.	Rahar.	Guar.	[illegible]
27th July	Day	10	93·5	...	78	·57	·55	·65	·87	[illegible]
28th ,,	Night	14	..	80·4	...	·12	·15	·16	·18	·15
28th ,,	Day	10	93·3	.	83	·66	·70	·81	·95	·71
29th ,,	Night	14	..	78·9	.	·15	·15	·19	·19	·17
						Wheat.	Barley.	Oats.	Peas.	Gram.
29th January	Day	10	73·7	..	69	·35	·49	·46	·80	·81
30th ,,	Night	14	..	41·8		·06	·06	·07	·16	·06
30th ,,	Day	10	74·5		65	·34	·48	·44	·90	·67
31st ,,	Night	14	.	39·7	...	·04	·07	·07	·18	·04
31st ,,	Day	10	76·7	.	64	·36	·50	·44	·94	·7
1st February ...	Night	14	..	42·2	...	·08	·13	·09	·20	·16

These data illustrate the marked difference between the amounts of water transpired during the day and night respectively and at the same time show how the season also affects the process. In July, the amount transpired during 14 hours of the night is about one-fourth as much as during 10 hours of the day time; in January the relative proportion is about 1 : 8. The temperature change in July was about 15°F., in January about 30°F.

The period of greatest water requirement.—An inspection of the charts shows the period during which the major part of the water is transpired. Since the *measurable* transpiration in these jars only commences when the plant is a few inches high, it is only charted from this period, and consequently the curve does not commence until some days after sowing. It rises rapidly immediately the plant commences to "shoot" and remains high, excepting during wet weather, until very near the time of maturity, when it falls again rapidly. It is of interest to tabulate

from the curves and other data the periods during which water is most required.

STATEMENT XXVI.

Season.	First period sowing to first rapid development.	Days.	Second period during which most water is required.	Days.
	Cold weather.			
Wheat 1907-08	Oct. 30th Nov. 30th	30	Nov. 30th March 29th	119
Do. 1908-09	Nov. 5th Dec. 1st	25	Dec. 1st March 28th	110
Oats	Oct. 21st ,, 4th	43	,, 4th March 4th	90
Barley	Nov. 2nd ,, 1st	28	,, 1st March 4th	94
Peas	,, 2nd Nov. 24th	20	Nov. 24th Feby. 28th	96
Gram	,, 2nd Dec. 9th	37	Dec. 9th March 9th	90
Linseed	,, 2nd ,, 4th	32	,, 4th March 9th	95
	Monsoon.			
Sarson	Oct. 20th Nov. 9th	19	Nov. 9th Jany. 31st	81
Maize 1907	July 23rd Aug. 12th	20	Aug. 12th Oct. 18th	68
Maize 1908	June 8th June 23rd	15	June 23rd Aug. 30th	86
Maize Akola soil 1908	July 4th July 20th	16	July 20th Sept. 30th	71
Maize Palur soil 1908	June 30th July 18th	18	,, 18th Sept. 26th	70
Shillong soil 1908	July 9th July 30th	21	,, 30th Sept. 27th	58
Murwa	June 9th July 9th	31	July 9th Sept. 18th	71
Kodo	June 10th July 21st.	11	July 21st Oct. 12th	83
Juar	June 15th June 26th	11	June 26th Sept. 29th	95
Rice	June 10th July 11th	31	July 11th Dec. 8th	150
Guar	June 11th June 26th	15	June 26th Nov. 23rd	150
Rahar	June 11th			...

The average ratio.—From the data obtained, the following average ratios have been deduced :—

STATEMENT No. XXVII—AVERAGE RATIOS.

Crop.	Unmanured.	Manured.
Cold weather crops.		
Wheat	850	550
Barley	680	480
Oats	870	550
Linseed	1000	1000
Sarson	740	620
Peas	830	530
Gram	1400	1000
Monsoon crops.		
Maize	450	330
Juar	400	400
Murwa	250	250
Kodo	300	300
Arhar	1,000	600
Guar	1,100	600

From these rice has been excluded; the plant grew very well, and produced a good weight of seed, but this was in less proportion to the straw than is, I think, common in the field, and the seed was smaller than normal. A more potent reason for its

exclusion lies in the fact that it was grown like "dry-land" rice and not with water on the surface of the soil. As a matter of fact, whatever the ratio for rice may be within reasonable limits, the water which its ratio represents per acre cannot bear any proportion to the total water used for wet-land paddy cultivation, and which amounts to something like 100" or more. Regarding the other ratios, they are useful for the purpose of an approximate estimate of the amount of water required per acre.

As regards the remainder of the crops which have been brought under experiment, most of them have only been under observation for a single season. This does not in itself deduct much from the value of the ratios obtained, because in those cases where repeated tests have been made, namely, wheat and maize, the first ratios obtained have been very well substantiated by the subsequent tests. The chief element of doubt depends on the fact that they have been obtained by experiment in one soil only, and the effect of this factor remains at present an open question. They may, however, be relied on for all soils of the great alluvium.

Another point of some little importance is that they are all probably somewhat *high*. In a previous paragraph (p. 163) it has been shown that the ratio depends in part on the mass of soil in which the plant is developing, a high ratio being obtained when the quantity of soil is only small. It is probable that the ratio in the field is distinctly smaller than those quoted, but at present it is not possible to accurately estimate the difference.

The amount of water required by a crop.—That the amount of water required to grow a crop depends largely on the weight of the crop is self-evident, so that even with a knowledge of the transpiration ratio, an equally accurate knowledge of this second factor is essential in order to estimate the total requirement. It will be also readily recognised that since the outturn of crops varies within considerable limits, it becomes impossible to say how much water is required for say, "a Wheat crop" or "a Juar crop." The most one can do is to assume the position of the agriculturist who, having a knowledge of the general weight of his crops, can calculate with the aid of the transpiration ratio the

total requirement in any specified case. With this object in view the quantities which are set out in statement No. XXVIII have been calculated. It is, however, to be recollected that they are the *quantities transpired*, and do not show how much irrigation water may be needed. It has been assumed that in round numbers an "unmanured" crop (grain and straw) will weigh 1,000 lbs., that a liberally manured one will weigh 5,000 lbs. per acre. If a crop weighs more than 5,000 lbs., the same ratio may be employed as has been adopted for 5,000 lbs. without serious error. These figures may be called in question to a certain extent, especially the one for "unmanured" land, because 1,000 lbs. is certainly very small. But against this is the fact that the pot-culture grown plants in unmanured soil are much smaller than one commonly gets in the field without the aid of manure. The effect of mass of soil in controlling the ratio has been already discussed, and I am sure from certain data which we have obtained in the field, that it has its effect there just as much as in the pot-culture house. Accordingly we must assume that the ratio for unmanured crops grown in the field is not so high as the one obtained with unmanured soil in the pot-culture house. But so far as this point is concerned it is not of first importance, because clearly what we desire more particularly to know is the amount of water required for *large* crops.

If then we consider the higher ratio obtained for plants grown by pot-cultures as true for a very small field crop, and the lower one, obtained by pot-cultures with manured soil as true for a heavy field crop, and adopt intermediate ratios for crops of intermediate weight, we shall probably be as near to the truth as is at present possible. This has been done for the purpose of the estimates set out in the statement. The quantites of water are stated as tons per acre, and as inches. Rainfall is always measured in the latter manner, and irrigation water can be expressed as readily in this as in any other way. The third line of figures against each crop is the most interesting.

The two pulses Arhar and Guar require more water than the other four monsoon crops, and linseed and gram similarly

STATEMENT XXVIII.

Cold Weather Crops.

		Assumed weight of crop in lbs. per acre.				
		1,000.	2,000.	3,000.	4,000.	5,000.
Wheat	Ratio	850	775	700	625	550
	Tons per acre	378	693	940	1,120	1,230
	Inches	**3·7**	**6·8**	**9·3**	**11·0**	**12·1**
Barley	Ratio	680	630	580	530	480
	Tons per acre	304	564	778	954	1,070
	Inches	**3·0**	**5·6**	**7·7**	**9·4**	**10·5**
Oats	Ratio	870	790	710	630	550
	Tons per acre	387	712	950	1,130	1,230
	Inches	**3·8**	**7·1**	**9·4**	**11·1**	**12·1**
Linseed	Ratio	1,000	1,000	1,000	1,000	1,000
	Tons per acre	448	892	1,340	1,780	2,240
	Inches	**4·4**	**8·8**	**13·2**	**17·6**	**22·1**
Sarson	Ratio	740	710	680	650	620
	Tons per acre	330	635	911	1,160	1,380
	Inches	**3·3**	**6·3**	**9·0**	**11·5**	**13·7**
Peas	Ratio	830	750	680	600	530
	Tons per acre	370	670	913	1,070	1,180
	Inches	**3·7**	**6·6**	**9·0**	**10·6**	**11·7**
Gram	Ratio	1,400	1,300	1,200	1,100	1,000
	Tons per acre	625	1,160	1,600	1,970	2,230
	Inches	**6·2**	**11·4**	**15·8**	**19·4**	**22·0**

Monsoon Crops.

		Assumed weight of crop in lbs. per acre.				
		1,000.	2,000.	3,000.	4,000.	5,000.
Maize	Ratio	450	420	390	360	330
	Tons per acre	200	380	524	645	735
	Inches	**2·0**	**3·7**	**5·2**	**6·3**	**7·2**
Juar	Ratio	400	400	400	400	400
	Tons per acre	178	367	536	715	895
	Inches	**1·8**	**3·5**	**5·3**	**7·0**	**8·8**
Murwa	Ratio	250	250	250	250	250
	Tons per acre	112	224	336	448	560
	Inches	**1·1**	**2·2**	**3·3**	**4·4**	**5·5**
Kodo	Ratio	300	300	300	300	300
	Tons per acre	134	238	402	536	670
	Inches	**1·3**	**2·3**	**4·0**	**5·3**	**6·6**
Arhar	Ratio	1,100	970	850	720	600
	Tons per acre	491	870	1,130	1,290	1,340
	Inches	**4·9**	**8·6**	**11·2**	**12·7**	**13·2**
Juar	Ratio	1,100	970	850	720	600
	Tons per acre	491	870	1,130	1,290	1,340
	Inches	**4·9**	**8·6**	**11·2**	**12·7**	**13·2**

a good deal more than the other cold weather crops. But what is still more striking is the fact that, broadly speaking, the cold weather crops transpire a good deal more water than those of the monsoon season. Since it is generally recognised that more rain is required during the monsoon period than the cold weather, the practical agriculturist may be inclined to doubt the correctness of the estimates, but apart from the fact that there is no legitimate reason for doubting the ratio obtained by pot-cultures to a greater extent than has been already suggested, there are several agricultural features *apart from the crop* which will readily account for the greater water requirement of the monsoon period. In the first place, it must be recollected that, at the end of the hot weather, the upper soil is so desiccated that a very considerable amount of rain is required before any crop can be expected to grow. Then too the amount of water lost by direct evaporation from the land during the monsoon must be for most soils greater than during the dry weather. The reason for this is simply that a larger amount of water is quite near the surface of the soil during wet weather than later on, when the upper foot or two feet are partly dry. A proof of this statement is also provided by the Rothamsted drain-gauge data which show that evaporation is greater in a wet year than in a dry one. Again, when considering the effect of humidity on transpiration, the small ratio of the monsoon crops, Maize, Juar, Ragi, Kodo in comparison with the others has been shown to be probably attributable to the nature of the crop, which has for generations become accustomed to growth in the more humid atmosphere of the monsoon period. Finally, in so far as a necessity for an abundant monsoon rainfall is concerned, it is to be recollected that one of its important functions in Upper India is the provision of a thoroughly damp soil for the succeeding cold weather crops. There are thus several reasons for experiencing no surprise that some at least of the rains crops require comparatively little water for *transpiration* purposes. The cold weather crops, on the other hand, develop in a comparatively dry atmosphere, which would naturally tend to cause a more vigorous transpiration.

In conclusion, reference may be made to the influence which the soil has on this subject. In some places where the soil is only a couple of feet thick, as in parts of the Deccan, quantities of irrigation water which are far in excess of those set out in the statement No. XXVIII are known by practice to be necessary: in other places, one or two irrigations, say 2″—4″ is sufficient to produce heavy cold weather crops; again, in Behar much of the soil is capable, provided it has been fallow during the monsoon, of producing, with the aid of manure but without rain or irrigation, very heavy crops. During the past cold weather for instance, such crops were produced, after a weak monsoon, with only ·35″ of rain during the cold weather. I am sure this aspect of the subject will be readily appreciated. It is indeed not only a question of how much water crops transpire, but also to what extent a soil acts as a ready reservoir of water. That soils vary in this respect was shown by Hellriegel, but it is doubtful whether its full significance has been generally appreciated. Whilst large cold weather crops could be grown in the soil at Pusa without any rain, the soil at Cawnpore, also liberally manured, could only produce very moderate ones; and yet the difference in the initial amount of water in the upper soil in the two places was only nominal. The quantities of water mentioned in the statement as being necessary for the transpiration requirements of cold weather crops probably provide an index of the maximum water which might have to be given either as rain or irrigation water in the great alluvium, but in how far the water which is in the soil at the conclusion of the monsoon assists the plant and so reduces the amount of irrigation water or rain required, must depend on the nature of the soil itself. The root range is naturally of importance and more information regarding it is required, and the capability of a soil to "yield" its water to plant roots is of equal importance.

PREFACE.

I would like to express my thanks to B. P. Standen, Esq., and G. F. Keatinge, Esq., Directors of Agriculture in the Central Provinces and Bombay, respectively, for having kindly arranged tours for me. Also to Messrs. D. Clouston, G. Evans, T. F. Main, W. Roberts, R. W. Wood, and others who have so kindly provided me with samples of soil for this investigation.

Dr. Leather has helped me with his wide knowledge of Indian soils, and I have also to thank the Assistants to the Imperial Agricultural Chemist for the help rendered in carrying out various analyses.

H. E. A.

Pusa,
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THE NATURE OF THE COLOUR OF BLACK COTTON SOIL.

BY

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INTRODUCTION.

THE black cotton soil of India covers an area of at least 200,000 sq. miles and ranks as the second most important of our Indian soils. On it by far the largest proportion of our Indian cotton crop is grown.

The origin of the soil and the cause of its dark colour have long been matters of discussion.

As far back as 1829 this soil was described by Christie.[*] From that date there has been a succession of papers dealing with it: the principal writers having been Newbold,[†] Hislop,[‡] W. T. Blanford,[§] Oldham,[¶] and Leather. These, however, dealt more with the origin of the soil than with the cause of its colour and most of the writers assumed the colour must be due to organic matter. Other theories have been advanced and will be enumerated further on in this paper.

Some years ago Captain A. Aytoun, R.A., published an interesting pamphlet on the "Origin and distribution of the Black Cotton Soils of the Indian Peninsula." He suggests that the black colour is due to organic matter, and that the black soil is

[*] *Edin. Phil. Jour.*, VI, 119 (1829): VII, 50 (1829).

[†] Proc. Roy. Soc., IV, 54 (1838).

[‡] *Jour. Bo. Br. Roy. As. Soc.*, V, 61 (1853).

[§] Memoirs, Geol. Survey, VI, 235 (1869): Records, VIII, 50 (1875).

[¶] Records, Geol. Survey, IV, 80 (1871).

[‖] *Agric. Ledger*, 1898, No. 2. Soils.

formed in depressions where marsh-loving plants grow up and die. He thinks that it is probable that the cotton plant has degenerated in India and that this degeneration is due to the gradual exhaustion of the soil.

Dr. Leather took up the question about twelve years ago, and made an investigation into the cause of the colour, though he did not quite settle the question. He was never able to finish his investigations, but he came to the conclusion that the colour of the soil was not due to organic matter but to the presence of some black mineral.

Besides the colour of the soil, another point which seemed to need investigation is the wonderful power the soil has of cracking during dry weather. The rents thus formed are constant sources of danger to the horseman riding through the black soil country. In some of the previous writings on the subject, the idea seemed to prevail that the substance causing the black colour was also the constituent which imparted this cracking power to the soil.

One hears tales of the wonderful fertility of certain tracts of this country, and therefore one would expect to see a fairly thick growth of natural vegetation. But a more disappointing outlook than is to be observed at those times when there are no crops on the ground, it is hard to imagine. Bare flat-topped hills of trap rock are typical of the black soil country and always give the traveller notice that he is approaching this type of soil.

The only tree which seems to grow on the soil is the Babul (*Acacia arabica*). Other trees there are practically none. It has been suggested that the roots of no other tree can endure the cracking which goes on in the soil in the dry weather.

The crops grown on the soil are very varied. The main one is cotton. We also get juar, bajri, sugar-cane, wheat, gram, linseed, tur.

The colour of the soil is in many cases a very deep black, but it varies between this and a slaty grey colour. The depth of colour depends on how the soil has been treated or whether rain

has recently fallen on it or no. Wet land freshly stirred generally appears the blackest of all.

The varieties of black cotton soil are numerous. Typically it is a deep black soil. As we approach the hills, it thins out to a lighter colour, and becomes mixed with fragments of rocks. It is very noticeable that black soils occupy the valleys, and as the hills are approached, the colour changes to red.

At Surat, the soil appears to have been all alluvial in its formation. It contains no pebbles of any kind, even Kankar* is rare, and it does not vary in colour throughout its whole depth. In the south of the Bombay Presidency around Dharwar, Hubli, etc., the soil contains numerous small pieces of Kankar.

The nature of the colour of black cotton soil therefore seemed to call for investigation, and Dr. Leather suggested to me that I should take the matter up since owing to pressure of other matters he was unable to do so himself.

Some of the theories which have been advanced at various times as to the cause of the black colour are rather quaint. It was once suggested to Dr. Leather† that the colour was due to the presence of a plant which exuded a black dye from its roots.

The presence of organic salts of iron is also suggested in a D. O. letter from Mr. Oldham to Dr. Leather.‡

As pointed out by Leather, this view cannot be entertained, owing to the great rate of oxidation in these soils at the high temperature.

Oldham§ and Medlicott and Blanford state that "the essential character of a dark colour appears to be due in all cases to the admixture of organic matter, and perhaps the presence of a small quantity of iron." These statements seem based on analyses by Tween. Leather points out that these analyses

* Pieces of carbonate of lime.

† *Agricultural Ledger*, 1898 No. 2, Soils.

‡ *Agricultural Ledger*, 1898, No. 2, soils, by J. W. Leather

§ Geology of India, 2nd edition, Oldham, p. 14.

Geology of India, Part I Medlicott & Blanford, pp. 133 4.

must have been carried out by igniting the soil, and hence the organic matter found includes combined water.

Leather came to the conclusion that the colour is *not* due to organic matter, but that it is due to the presence of some black mineral and that this might be graphite fused on to silicates. He also made analyses of large numbers of these soils. The reasons put forward by Leather to shew that the colour is not due to organic matter are the following :—

(1) The proportion of total nitrogen is as low as in most other soils which lose only $\frac{1}{2}$ or $\frac{1}{3}$ as much in weight when heated : this indicates a low proportion of organic matter.

(2) Although the loss on igniting the soils is almost uniformly high, it is suggested that the greater part of this loss is due to expulsion of combined water, because the manner in which these regur soils contract on drying, indicates a high proportion of hydrated ferric oxide or alumina and either of these compounds would lose the water of hydration on being heated.

(3) After boiling these soils with strong sulphuric acid to destroy all organic matter, the siliceous residue is still black.

Experimental.

Presence of a Black Mineral. On shaking up a sample of black cotton soil in a basin, I observed an appreciable amount of a black substance at the bottom of the vessel. All my samples of black soil were therefore tested for the presence of this substance. The samples were ground very fine, and then treated with very weak hydrochloric acid until no more effervescence took place. Each sample was then shaken up in a porcelain basin. By a process of "cradling," the muddy liquid was thrown off and more water was added, and the "cradling" process repeated From each of the black soils a residue was in this way obtained, which was seen to be very rich in these black particles. Specimens of many Indian soils, other than black soils, were treated in the same way, but no such black substance was obtained. The soils so treated were from Shillong, various soils from the Gangetic

alluvium, Bangalore, etc. Black soils from Surat, Broach, Poona and Bhusawal (Bombay Presidency), Nagpur, Akola, Betul (C. P.) and Samalkot (Madras) all gave a fair amount of the black substance.

On examining this black mineral, it was found to be strongly attracted by a magnet, and to be very rich in iron. The soil particles were next tested with a magnet, and the particles of all black cotton soils so far examined have been found to be magnetic. The particles of other soils were tested in a similar way. Such red soils as those of Shillong and Bangalore which contain much ferric oxide were also magnetic to a small extent, but to nothing like the same extent as the black cotton soils.

Hence it appears that these soils contain a black substance which is peculiar to them.

Prof. Hilgard, in a recent letter to Dr. Leather, detailing the results of his examination of two black cotton soils, reports that the "microscopic examination of portions of both soils proves the presence of a certain amount of magnetite, and also of some rather indefinite black particles which I take to be partly decomposed hornblende or augite, probably derived from underlying rock just as is the case in the soils resulting from the decomposition of our basalt soils, but the latter yield rather light soils, poor in humus and of reddish tint and nowhere anything like your Indian regur."

Amount of Black Mineral Present.—The presence of a black mineral having been established, it next remained to determine in what quantity it occurs, and also whether this quantity is sufficient to account for the black colour.

The most obvious method for determining the amount present seemed to be by the use of the magnet. However, although an electro-magnet was fitted up, it was not found possible to separate the black mineral satisfactorily by its means even when the soil was ground up with water and the magnet poles immersed in the liquid. Practically every soil particle is magnetic and is attracted to the magnet with the black substance.

After many attempts the following method was adhered to in order to estimate quantitatively the amount of black substance present.

25 grms. of the soil were finely ground in an agate mortar. It was then treated with 3 per cent. hydrochloric acid in a large porcelain dish until all calcium carbonate had been dissolved. The dish was then given a rotary movement in the hand. Thus the soil particles were set in motion and the heavy particles of the black mineral settled to the bottom. The muddy liquid was then decanted into a big beaker. More water was added to the basin, which was again rotated as above. The process was repeated many times and at last the residue in the basin consisted of the practically pure black mineral. This was collected. The soil which had been poured into the beaker was again cradled. This was placed with the first lot obtained. The process was repeated until the soil yielded no more black mineral in this way.

The amount of black mineral obtained in this manner from various soils is here set out :—

	Per cent. of black mineral by weight
Surat soil (1)	2·5
Ditto (2)	1·8
Ditto (3)	1·5
Ditto (4)	1·6
Ditto (5)	1·8
Chikoli, Berar (1)	1·5
Ditto (2)	3·0
Yeotmal, Berar	1·8
Akola, No. 1	1·3
Samalkot, Madras	0·3

It must be remembered that all the black substances have not been removed from the soil by this method. The particles of soil left behind were still magnetic. Only the black substance which is loose in the soil has been thus separated.

It is next desirable to know how much black substance is necessary in order to give a black appearance to the soil. Various amounts of magnetite were added to equal weights of Pusa soil which is very light coloured. When 10 per cent. of the black substance was present, then the soil was very dark.

5 per cent. was found to darken it considerably and even 2—3 per cent. had a great effect. From my experiments I concluded that with a soil which is already a little dark the addition of 3—4 per cent. of magnetite would cause a very appreciable darkening, but not enough to account for the very deep black colour of some of these soils.

It next seemed desirable to try and devise a chemical method for the estimation of the amount of black substance present. After many attempts, however, it was found impossible to do this.

On boiling the soil with strong sulphuric acid as in the Kjeldahl process, the residue obtained in the case of all black cotton soils is more or less black, whereas the residue from all other soils is either white or white and red. This fact was observed by Leather (*Agricl. Ledger*, No. 2, 1898, p. 20).

This residue was still found to be magnetic on washing and drying. On boiling these black residues with hydrochloric acid for some hours, however, and washing and drying, they were found to be no longer magnetic. On again boiling the residues in sulphuric acid, a pure white residue was now obtained which was non magnetic.

It occurred to me therefore to estimate the amount of black substance present in a soil by first boiling it with sulphuric acid and then estimating the amount of iron which goes into solution by boiling the residue with hydrochloric acid. However, the results obtained by this method were no better than those obtained by mechanical separation owing to the fact that the pure black substance was found to be soluble to a large but variable extent in sulphuric acid.

A few of the results thus obtained may, however, be here quoted: 20 grams each of Pusa and Surat soils and of two soils from Akola farm (Central Provinces), were boiled with sulphuric acid as in the Kjeldahl process but without addition of potassium sulphate. Also an extra lot of 20 grams of Pusa soil to which 5 per cent. of magnetite had been added was similarly boiled. The boiling was continued until all carbon was destroyed. The residues in each case were then collected and washed free from acid. The

residue from Pusa soil without magnetite appeared white. The residues from the three black soils (Surat and Akola) contained many black particles, but there was *no* red oxide of iron visible. The residue from the Pusa soil to which magnetite had been added was seen to contain a good deal of black substance. The iron was now determined in each residue by boiling it for 8 hours with hydrochloric acid on a sand bath, filtering and estimating the iron in the solution with potassium dichromate.

The following table shews the results :—

Soil.	Iron found calculated as magnetite Fe_3O_4.
	per cent.
Pusa (without magnetite)	·04
„ (with 5% ditto)	2·20
Surat soil	1·00
Akola soil No. 1	2·06
Ditto „ 2	2·25

The solubility of the black substance has been found to be somewhere about 55 per cent. in strong sulphuric acid. About 35 of the magnetite added to the Pusa soil has been dissolved, so if all the iron is present as magnetite the Surat soil appears to contain 2—3 per cent. and the Akola soils 4—5 per cent. of magnetite.

These figures are naturally very approximate, but they are given as being perhaps some indication of the amount of black substance present in these soils.

An attempt was made to separate the black substance by the use of Thoulet's* solution. This was obtained of a sp. gr. 3·1, but the results with it were not satisfactory. The figures obtained tallied roughly with those obtained by the method of mechanical separation, as was to be expected.

Analysis of Black Substance.—A qualitative analysis shewed the mineral to be mainly magnetite, containing fair quantities of titanium and small amounts of magnesium.

Purification was carried out by grinding with water in an agate mortar and then extracting with a magnet. The substance

* *Wiley's Agric. Analysis, Soils*, Vol. I. p. 297 (1906).

extracted was again ground and extracted. This process was repeated until microscopic examination shewed the substance to consist of the pure black mineral.

Quantitative analyses of the black substance from various soils were then carried out and are here quoted :—

			Surat Soil.		
			Sample I	Sample II	Yeotmal, Berar.
Iron as Fe_3O_4	...	...	77·10	68·73	70·90
Titanium as TiO_2	...	...	19·09	14·67	21·75
Magnesium as MgO	...	...	3·51	16·60	7·35
	Total	...	100·00	100·00	100·00

The iron, titanium and magnesium were determined, and after satisfying myself that the remainder was earthy matter, I assumed in the calculations that the substance consisted of Fe_3O_4, TiO_2 and MgO. This was done as it was found impossible to get the substance *entirely* free from earthy matter. One analysis, however, may be quoted to shew to what extent of purity I was able to bring the samples.

Surat Soil I.

Fe_3O_4	...	...	...	...	73·24
TiO_2		...	.	...	18·07
MgO	...	...	..	...	3·32
					94·63

Method of analysis.—The *iron* was determined in the hydrochloric acid solution with titanous chloride.*

Titanium was estimated in the hydrochloric acid solution after reduction with zinc by titration with methylene blue.† This method, after a little practice, was found to give excellent results. On boiling the black substance with hydrochloric acid an insoluble residue was left which contained much of the titanium. This was fused with caustic potash and then dissolved in hydrochloric acid. The titanium was then estimated in this solution by reduction with zinc and titration with methylene blue as before.

* *Sutton's* volumetric analysis.

† *J. S. C. I.*, Feby 27th, 1909, Eva Hibbert.

Magnesium was determined as pyrophosphate.

The proportion of ferrous to ferric iron was determined in a sample of the black substance obtained from Surat soil. The result obtained was, total iron found 53·01 per cent.; ferrous iron found 16·74 per cent.; ferrous iron for Fe_3O_4 theory 17·67. Assuming the iron is present as magnetic oxide, this result is quite satisfactory. In any case a lower result than the theory for ferrous iron would be expected since the magnesium present probably has displaced some of the ferrous iron.

The method used for determining the ferrous iron consisted in dissolving the substance in hydrochloric acid in an atmosphere of carbon dioxide and then to titrate with potassium permanganate after adding manganous sulphate.*

Properties of the black substances.—The substance when isolated is in the form of lustrous black crystals.

Its sp. gr. is about 5·7. It is only partially soluble in boiling sulphuric acid. After boiling for three hours about 55 per cent went into solution. This explains why black residues are obtained on boiling these soils with sulphuric acid. It is no more soluble in nitric acid.

It is readily soluble in boiling hydrochloric acid, though a small residue of titanic oxide is left behind.

It is attracted by a magnet though much less readily than pure magnetite; in fact, some particles of it are only with great difficulty picked up with a magnet.

Occurrence of Black Sands in America.—In certain of the Western States of America black sands occur associated with the soils. These sands chiefly occur in Oregon and California, and O. H. Hershey† makes reference to their occurrence on the Isthmus of Panama.

Many investigations have been made into the composition of these sands. The magnetite occurring in them usually contains from five to ten per cent. of titanium and constitutes a greater

* *Chem. News*, 99, 61, 73

† A remarkable deposit of black iron sand, Isthmus of Panama. O. H. Hershey, M and Sci. Press, Oct. 22, 1898.

supply of useful iron than any other available source known on the Pacific coast.*

Associated with these black sands in America, however, are appreciable quantities of gold and platinum, especially of the former.

So far I have been unable to find gold in the black substance I have isolated from the soils, but I have only been able to obtain small quantities of it at present.

Along the banks of most of the rivers in the Deccan and also of the Tapti at Surat may be seen quantities of a deep black sand washed up by the river. These rivers all flow through trap rock districts and black soil, and thus we have another indication of the presence of appreciable quantities of this black substance in the soils. I collected several samples of this black sand from the Tapti at Surat, from the Tapti at Bhusawal (Bombay Presidency) and several other places. The following is an analysis of a sample collected at Bhusawal.

$Fe = Fe_3O_4$	75·09
$Ti = TiO_2$	14·33
$Mg = MgO$	9·16
$Ca = CaO$	1·42
	100·00

After heavy showers of rain in the black soil country I have often noticed a deposit of black sand in the little gullies scoured out in the roadside by the rain.

Oldham† says "many of the dolorites of the Deccan contain iron in the form of magnetite and large quantities of magnetic iron sand are found in the beds of streams which flow over the trap, whilst bands both of magnetite and hæmatite are locally common in the metamorphic rocks." On p. 380 Oldham goes on to say: "It has been stated that magnetite occurs in many of the Deccan basalts, but until far more analyses have been made, it is impossible to say whether any of the rocks contain as large

* Black Sands of the Pacific Slope in 1905, D. T. Day and R. H. Richards, Dept. of the Interior, U. S. Geol. Survey.

† Geology of India, p. 379.

a proportion of iron as the laterite. It is probable that some may, but 15—20 per cent. in any basalt is exceptional."

Amount of Organic Matter present in the Soil.—As mentioned on a previous page, various writers have considered the black colour to be primarily due to the presence of organic matter. I have also set out the chief reasons put forward by Leather to shew that this explanation of the colour cannot be entertained. In addition to this, black cotton soil has been generally considered of late years by officers of the Agricultural Department to be deficient in organic matter. Thus Clouston in a paper on Manuring of Cotton* in the Central Provinces mentions that it is a well known fact that black cotton soils are deficient in humus, and also he says the cracks help to aerate the soil and thus humus would have more chance of being oxidised. He advocates the use of organic manure and says that nitrogenous manures are found to have a great effect.

Also at certain hilly districts in Bombay, *e.g.*, at Lonavla, it has been found that cake manures and artificial nitrogenous manures have a wonderful effect on plant growth, indicating the soil to be poor in organic matter.

However, Oldham† notes that Leather did not determine organic carbon in these soils and says this would seem to be an important point.

Hilgard‡ also says: "Leather attributes the black colour of the regur to some mineral substance rather than to humus, but his arguments are not quite convincing so long as the Grandeau test has not been made."

It therefore seemed advisable to determine both the organic carbon and the soluble humus in these soils.

Owing to the absence of gas, etc., the earlier determinations of organic carbon were done by the wet combustion or chromic acid method.

* *Agricultural Journal of India*, Vol. II, Part II.

† See letter in *Agricultural Ledger* (Leather), 1898, No. 2, p. 24.

‡ *Soils*, Hilgard, p. 415.

Later, however, since the completion of the Agricultural Research Institute, determinations have been carried out by the dry combustion method with copper oxide in a current of oxygen. The latter method, however, besides involving the determination of the amount of carbonate present in the soil, also involved a determination of the alkali carbonates left behind after the combustion, in the soil residue. Had the amount of these latter not been determined, a considerable error would have resulted.

The figures obtained are expressed as percentage of organic carbon in the soil, it not being considered desirable to express this as organic matter by multiplying by any factor.

In the cases where the carbon was determined in the same soil by both methods, the figures are given for the purpose of putting on record the difference to be expected in the results obtained. The amount of organic carbon found in various other Indian soils is also set out.

	Soil taken.	Per cent. organic carbon. Wet combustion method.	Dry combustion method.
	(1) Akola soil	...	·83
	(2) 1st class black cotton soil	·94	1·10
	(3) 2nd	..	1·00
	Surat soil	·49	·70
	Samalkot soil (Madras) ...	...	1·16
	Akola survey No. 58 ...	·68	...
	6 miles north of Sukhtawa (sandstone)	...	0·82
Not black cotton soil	Pusa	0·46	
	Shillong	...	2·63
	Bangalore	...	0·46
	Sandy soil, Woburn, England, barley after wheat ..	...	1·19
	* Pasture (Rothamsted) 0″–9″ ...	.	3·60
	* Broadbalk .. 0″–9″ ...	...	1·57
	* Geescroft .. 0″–9″ ...	...	1·13

The chromic acid method therefore gives lower results than those obtained by combustion in Oxygen. This was also found to be the case by Warington and Peake,† and by Cameron

* J. C. S., 1906 (89) 595, Hall, Miller & Marmu. *

† Trans. C. S., 1880, 37, 617.

and Brazeale.* Hall, Miller and Marmu† shewed that by the addition of a short tube containing red hot copper oxide to complete the combustion the whole of the carbon in the soil can be obtained as carbon dioxide.

The amount of organic carbon in these typical black cotton soils is therefore not unusually high. So that from these figures one could hardly say that the black colour is due to the presence of organic matter.

Soluble Humus.—This was estimated by the method recommended by the U. S. Department of Agriculture.‡

10 gms. of the soil were washed in a Buchner funnel with 1 per cent. hydrochloric acid till the filtrate was free from lime. The soil was then washed with water until the washings were no longer acid. It was then transferred to a stoppered cylinder together with 500 c.c. of 4 per cent. ammonia and allowed to remain with occasional shaking for 24 hours. After standing a further 12 hours an aliquot portion of the liquid was filtered off through asbestos and evaporated to dryness in a platinum basin. The dried residue was weighed and then ignited. Another weight was then taken. The loss of weight is equal to the soluble humus.

	Soil.	Soluble humus per cent.
	Akola No. 1	1·33
	Yeotmal, Berar	1·86
	Surat	0·91
	Samalkot	1·50
	Akola No. 2	1·25
	Akola (Hilgard)	0·70
	Nagpur (Hilgard)	0·90
Not black cotton soil	Shillong	2·49
	Pusa soil (sandy)	0·69
	„ (clay)	0·89

From the amounts of soluble humus and organic carbon found we cannot say that black cotton soils are rich in organic matter. If we compare the amount of organic carbon in these

* *Jour. Amer. C. S.*, 1903, 26, 29.

† *J. C. S.*, 1906, 89, p. 595, Hall, Miller and Marmu.

‡ Official and Provisional Methods of Analysis, Association of Official Agricultural Chemists, 1908.

soils, however, with the amount of soluble humus, a very interesting fact is observable. The total organic matter in a soil is often calculated from the amount of organic carbon found by multiplying the amount of this by a factor. Thus Hall * states that the organic matter in the soil is sometimes assumed to contain [illegible] per cent. of carbon. We can therefore roughly assume the organic matter in the soil to contain about half its weight of carbon.

On looking at the analyses of black soils we find that Samalkot soil contains 1·16 per cent. of organic carbon and therefore should contain about 2 per cent. of total organic matter. The soluble humus in it, however, is 1·50; *i.e.*, most of the organic matter is in the form of soluble humus. The same is the case with the other black soils examined. But with other soils, such as Shillong soil, we find the organic matter is well over [illegible] per cent., though the soluble humus only amounts to 2·49 per cent. The same thing is noticeable with Pusa soil. Thus in black cotton soils the organic matter appears to be largely present as soluble humus.

Although it appears improbable that so small an amount as 1–2 per cent. of humus could have an appreciable effect on the colour of the soil, it was thought desirable to test this point. Accordingly various black soils were treated with hydrochloric acid to decompose the "humates" and then washed free of acid.

Each soil thus treated was now divided into two equal portions, one of which was then shaken with 4 per cent. ammonia solution and allowed to settle. The soluble humus was thus extracted and the colour of the soil remaining was compared with that of the portion of soil which had not been treated with ammonia. In every black soil examined the portion extracted with ammonia was distinctly lighter in colour than the other portion. A light coloured Pusa soil containing only 0·69 per cent. soluble humus showed no such difference in colour after ammonia treatment, whereas a Shillong soil containing 2·49 per cent. soluble humus

* *The Soil*, 19[illegible]3 edition, p. 143.

became much lighter in colour after ammonia extraction. The black soils examined were from Surat, Samalkot, and three from the Central Provinces.

These experiments prove that although the amount of humus is not very high in these soils, yet the dark colour is partly due to its presence.

The Cracking of the Soil.—As mentioned already, this soil is noted for the large cracks which form in it during dry weather. Some observers have supposed this property to depend in some way on the presence of the black substance which causes the colour.

It seemed, however, far more likely that it was due to the presence of a large proportion of clay. Accordingly the amount of clay was determined in a number of soils. The amounts found are set out in the table.

	Without preliminary acid treatment.	With preliminary acid treatment
Akola 1st class B. C. soil	.. ...	59·50
Akola black cotton mixed with red	...	31·18
Surat	......	42·15
Samalkot, Madras	......	59·09
Akola survey No. 51	16·83	26·04
" 12	26·61	48·25
" 58	19·19	23·30
Amrai Farm field, Berar ...	15·90	35·74
Hagari Farm, Bellary ...	16·39	30·78

The method for the clay determination was the sedimentation method described by Hall.* In the second column the sample of soil was first treated with N/5 hydrochloric acid† to dissolve carbonate. In the first column some figures are given which were obtained after simply boiling the sample for half an hour in water instead of the preliminary acid treatment.

As will be seen, the acid treatment shews a much higher proportion of "clay."‡ It was thought worth while to put both sets of determinations on record here.

* *The Soil*, 1908, p. 51.

† *Schloesing, Compt. rend.*, 1874, 78, p. 1276.

‡ See also *Hall, Jour. Chem. Soc.*, 1904, Vol. 85, p. 96?

The separated "clay" apparently consisted of much finer particles than usually occurs in soils.

It is therefore quite obvious that the high proportion of clay would in itself account for the "cracking" in these soils.

A practical point here however arises. These soils, though mostly heavy clay soils, behave rather differently from heavy clays such as are known in England. These latter require very careful treatment after rain, and if ploughed when too wet turn up into large unbreakable clods which are only with great difficulty broken down when they dry. On the other hand, black soil can be kneaded up with water to form a very plastic mass, but when this dries, it can readily be broken to a powder. Wet clods of the earth in the field can readily be broken to a powder by gentle pressure. It occurred to me that the explanation of this might be found in the presence of the black mineral. Laboratory experiments on this point, however, did not lead to any very definite conclusion.

Chemical Composition of the Soil.—The composition of the soil does not vary within wide limits. The analyses given are typical ones.

	Nagpur Farm	Akola	Average of 18 soils.
Insoluble silicates and sand	68·71	56·11	68·41
Peroxide of iron (Fe_2O_3)	11·25	9·83	7·13
Alumina (Al_2O_3)	9·39	10·68	10·14
Manganese oxide (MnO)	·26	... ...	·17
Lime (CaO)	1·82	6·59	2·90
Magnesia (MgO)	1·79	2·51	2·27
Potash (K_2O)	·45	0·37	·41
Soda (Na_2O)		0·23	
Phosphoric acid (P_2O_5)	·06	0·08	·06
Sulphuric acid (SO_3)	nil		—
Carbonic acid (CO_2)	·44	4·18	1·02
Organic matter and combined water	5·83	9·42	6·58
Total Nitrogen	·05	·03	·03

All the above analyses except that of Akola soil were published by Leather,* though the average of 18 soils was actually

* *Agricultural Ledger*, No. 2. 1898.

taken from Hilgard* who averaged Leather's figures in his ... book.

In these analyses both the amounts of iron and of alumina are high. The latter indicates a large amount of clay, which has been found.

Numerous iron determinations have been made in these black soils.

The analyses by Leather shewed an iron content varying between 6 and 14 per cent. of Fe_2O_3

My own analyses have all shewn a similarly high iron content.

		Per cent. Fe_2O_3
Hagari Farm, Bellary, Madras	...	11·08
Yeotmal, Berar	...	11·53
Akola, No. 1	...	14·36
Surat soil	...	11·29
Samalkot	...	11·25

Origin of black soil.—The origin of black soil has long been a matter of discussion, but it seems to be fairly clear now that it is formed from the trap rock. But this is a question I do not propose to enter into here. A point which this paper does throw light on, however, is that the alluvial black soils such as those of Surat are similar to the sedentary black soils of the Deccan. These alluvial black soils are well seen at Surat (Bombay Presidency) and at Samalkot (Madras Presidency). Surat is at the mouth of the river Tapti and Samalkot at the mouth of the Godaveri and both these rivers flow through the trap districts for most of their course.

Reference may here be made, however, to an examination of some decomposing amygdaloid trap rock underlying black soil found at Bhusawal, Bombay Presidency. A sample of this was finely ground in an agate mortar under water. The fine powder was then cradled to separate any black substance as described on p. 188. The amount of black substance separated amounted to just under 5 per cent. of the rock.

* *Soils, Hilgard*, p. 412.

An analysis of this black substance gave the following figures :—

Iron	— Fe_3O_4	84·23
Titanium	— TiO_2	12·18

The black soil appeared to have been formed *in situ* from this "murum," and the above figures are interesting as indicating that a similar black substance appears to occur both in the decomposing trap rock and in the soil itself.

Conclusions.—1. The black colour of these soils is mainly due to the presence of several per cent. of titaniferous magnetite and of 1–2 per cent. of soluble humus. The mineral substance alone would not account for the deep black colour. Here it may be noted that the black colour of certain Hawaiian soils is in part attributed to mineral matter, in this case manganese dioxide.*

2. The soils are not rich in organic matter judged from the European standard, and organic nitrogenous manures appear to give good results on them.

3. The amount of clay is exceptionally high and this accounts for the "cracking" which takes place in these soils during the hot dry weather.

* J. Ind. & Eng. Chem., August 1909.

PREFACE.

This Memoir forms a sequel to No. 8 and provides further information regarding the water requirements of crops in India, as determined in soils other than that at Pusa, as also the results of determinations carried out in the field.

Nearly the whole of the experimental work has been executed by Messrs. B. M. Amin, B.A., A. V. Iyer, B.A., K. S. Viswanadham, B.A., and D. N. Chatterji, B.A., B.Sc., Assistants in the Chemical Section of this Institute, and by Babus Ganga Parshad Pande and Nand Kishore Saksena of the Cawnpore Agricultural Station. I desire to take this opportunity of acknowledging the care which they have bestowed upon the work.

My acknowledgments are also due to Mr. B. C. Burt, Deputy Director of Agriculture, United Provinces, for valuable assistance in connection with the Cawnpore section of the work.

PUSA,
January, 1911.

J. W. L.

CONTENTS.

WATER REQUIREMENTS OF CROPS IN INDIA II.

BY

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INTRODUCTORY.

IN Memoir No. 8 (Chemical Series) the results which had been obtained by measuring the amounts of water transpired by plants when grown by "pot-culture" methods were detailed, and the plan of the experiments was set out on page 143. It was there explained, p. 144, that in developing the work it had been decided to grow (*i*) a number of plants in one sort of soil, and (*ii*) the same plant in a variety of soils, but that details regarding the latter would be published separately. This course was necessitated by the fact that, although this section of the work was in part completed in the monsoon season of 1908, the cultures of the following cold weather season were a failure, chiefly owing to want of experience with some of the new soils. The difficulty was related to the physical properties of these soils and this matter will be explained subsequently. The test with the cold weather crops was repeated in the season 1909-10 and the whole data may now be published. In addition to this part of the investigation, it was felt to be desirable, since most of the plants mentioned in Memoir No. 8 had been cultivated in small jars holding about 15 kilos of soil, to grow some of them again in the large jars containing about 50 kilos of soil, in order to check the former transpiration ratios, and this was done in the cold weather season 1909-10. Part I of this memoir is devoted to this section of the work and to a discussion of the results.

In addition to these estimates of water requirements of crops by pot-culture methods, it occurred to me some four years ago to try to make observations in the field on the same subject.

It is generally acknowledged that results obtained by pot cultures should be, when possible, verified by similar experiments in the field, and however great the difficulty in estimating the water requirements of crops in this way, it was evident that if the pot-culture estimate could be even approximately checked, such confirmation would possess considerable value. Details regarding the method employed, the data obtained and the deductions which may be made therefrom are set out in Part II.

The Memoir also includes certain arguments and deductions in regard to movements of water in soils, and the importance of a method for the estimation of the rate at which water can move through soils is emphasised.

PART I.

Pot-Cultures.

As briefly indicated above, specimens of our field crops have been grown in the pot-culture house in order to ascertain the amount of water transpired from the initial stage of growth until fully ripe.

As regards details of the method, the reader may be referred to pp. 137-142 of Memoir No. 8 (Chemical Series), but some further notes are here of importance because of the fact that difficulties were experienced in the use of some of the soils.

Filling the jar.—Soils containing but little clay are best filled into the jars in a damped condition as previously described.* Thus the Shillong soil, which contains a high proportion of organic matter, and the Palur soil, could be filled in and pressed down into the jar in the same manner as the calcareous Pusa soil; but the highly argillaceous Black Cotton soil from Akola apparently became too closely packed when filled in this manner, and it was found necessary to only *shake* it, in the damped condition (1/4 water) into the jars. This was undoubtedly due to the fact that

* Loc. cit. p. 138.

this soil swells in quite an extraordinary manner when wet and hence the necessity for allowing a good deal more "interspace" than for the other soils.

Mode of adding Water.—The water used, clean well water, was for the most part added through the cylinders,* but this practice had to be varied in certain cases.

One of the most striking difficulties which we met with was related to the secondary root system of maize. The cereals, millets, etc., after producing the radicle and one or two leaves, develop the secondary "adventitious" root system from the node at the base of the first leaf. Shortly after this, the radicle stem below the first node ceases to functionate and dies off, and the plant depends on its secondary root system. It follows that if the surface soil, into which this secondary root penetrates, is moist, the further growth of the plant is assured: if, on the other hand, the surface soil is air-dry, this secondary root system cannot develop or at least may not get down to the moist soil before the primary stem has died off: the plant then withers. Now the rate at which moisture moves through the Black Cotton soil and the Shillong soil is apparently so slow that, although there was a fairly liberal allowance of water, 30% and 25%, respectively, in these soils *as a whole* in the first and second seasons, they became air-dry *at the surface* for about 3" deep, and the maize plants could not get their secondary roots through this dry soil before the lower part of the stem began to fail. In the monsoon of 1908 some of the maize had to be re-sown on this account, and all plants in the three soils from Akola, Shillong and Palur, respectively, had to be assisted. This was done by forming a small heap of soil round each plant and keeping this wet by surface additions of water until the plant had developed sufficiently to be independent in this respect. This procedure did not affect the transpiration ratio in any measurable degree because transpiration only becomes considerable after the secondary roots have made a vigorous start. Subsequently the drier the surface soil the better, since it was desired to reduce the loss due to simple evaporation as far as

* *Loc. cit.* p. 138.

possible; hence all water was subsequently added through the irrigation cylinders.

Bearing this difficulty in mind, it was decided to circumvent it in the cold weather of 1909-10 if possible by a different arrangement. What was obviously desired was to maintain the surface of these soils thoroughly moist: but if this were done in an unprotected manner, the direct loss by evaporation from the soil would undoubtedly be very high, and the error due to this would also be high. This point has been fully dealt with in the preceding Memoir (No. 8, p. 140). For reasons then explained close covers seemed to be objectionable; what was wanted was a cover which would, on the one hand, allow aeration of the surface soil, whilst on the other, it would prevent in a great measure the excessive evaporation. A layer of coarse gravel seemed to meet these requirements, for aeration would be very perfect, whilst the amount of water that would be conveyed over its surface by surface tension would be negligible and that which would pass out by diffusion of water vapour would probably be also small. Over the soil surface a single layer of rather coarse (¼"—½") pebbles and over this another inch of ⅛"—¼" gravel was laid. This "cover" served the end in view excellently; the growth of the plants left nothing to be desired, and the loss by evaporation was reduced to *less than* one-half that of the Pusa soil, instead of being much higher, whilst the soil was maintained quite damp to its surface.

A third deviation in respect of certain of these jars was found necessary. Some of the plants transpired upwards of [illegible] kilos of water per diem during their most vigorous stage, and it was found during this period that if the whole of this water were added in the morning after recording the weights, as has been the general custom, the plants ran short during the afternoon. It became necessary therefore to add water twice a day to two jars of Akola soil and to two of Pusa soil, the plants being sarson in each case. Moreover, to two of the Akola soil jars it was necessary, during the period of most vigorous growth, to add water at the surface. This introduced a further source

of error, for this addition of water through the gravel necessarily left the latter wet and would hence occasion a greater loss by evaporation from these jars than from the blank jars. It was found, however, that this excess loss was far less than we anticipated; apparently the gravel when wet held so little water that when this evaporated the loss from soil and gravel was not much greater than when the gravel was air-dry, and the error became negligible. In this respect reference may be made to Statements Nos. II & III in which the data relating to wheat and sarson are set out; from the manured wheat jars about 180 kilos of water were transpired against 11 evaporated; from the corresponding sarson jars the respective figures are about 130 against 8, so that whatever error might be introduced by wetting the gravel periodically during a part of the period of growth, such error could not affect the transpiration ratio materially. As has been said, however, the extra loss from the wet gravel was found experimentally to be only nominal.

Sowing.—Owing to the employment of the gravel it was anticipated that some provision would be necessary to keep the gravel off the plant in its initial stage. This proved by subsequent trial to be unnecessary, for if seeds are sown in the soil, the plantling is strong enough to force its way quite well through the $1\frac{1}{2}''$ to $2''$ of gravel. But at the time of sowing the jars, no risks of failure could be run, and hence the following device was employed. For each seed a small tube of brown paper, about $2''$ long by $\frac{1}{2}''$ diam. was inserted through the gravel on to the soil surface, and the seed placed in the soil. After the plants had come through, these paper cylinders were removed. Although subsequently found unnecessary, the device answered its purpose very well, though great care had to be exercised when removing the paper cylinders in order to avoid damaging the young plant.

Evaporation through the sides of jars.—Before passing to a consideration of the data obtained during the two seasons, reference may be made to some measurements of the amount of water which vapourises through the sides of these cultivation jars.

Since the publication of Memoir No. 8, a correspondent has raised the question whether such evaporation could have introduced any material error. Now, as was explained in that publication (p. 140), jars of soil of the same degree of moisture as the jars carrying plants are maintained in order to estimate the loss of water from the soil as distinct from the loss due to transpiration which the plant-bearing jars suffered. Since the jars are glazed no serious loss by vapourisation through their sides could very well take place, but in any case whatever such loss of water might be, it was necessarily included in the loss from the blank jars. It was also explained (p. 141) that the estimate of water lost by evaporation from the soil was open to some error, because no two jars of moist soil will evaporate exactly equal amounts. Moreover it has to be recognised in all this work that the loss by *evaporation* from soil bearing large leafy plants will presumably be less than if the same soil were freely exposed to the air. Indeed the method of estimating the loss from the soil, and hence the amount of water transpired, is only correct within certain limits. But to illustrate in how far its error affects our final result, namely, the transpiration ratio, take the case of wheat grown in Akola soil (Statement No. II). If the soil had evaporated 25 per cent. less than was estimated by the blank jars, the ratio for jar No. 13 (small plants) would become 945 instead of 849, whilst in the same way, the ratio for jar No. 19 (large plants) would become 428 instead of 422. As was pointed out previously (p. 176) the ratio for poorly developed plants is of comparatively little consequence, whilst the error we are discussing hardly affects that for well-grown ones.

However, inasmuch as the question of the amount of water which evaporates through the sides of these cultivation jars was raised, some measurements of its amount were made. To this end the following method was adopted. Stout india-rubber sheet was tied over the top of four jars, two of which contained Pusa soil with 20 per cent. water, and two Akola soil with 40 per cent. water; the daily loss was then recorded for a fortnight in the hot weather, *i.e.*, when such loss would be maximum, and was

found to be ·05, ·015, ·03, ·02 kilo. per day. The daily loss from these jars *uncovered* had been ·159, ·109, ·122, ·121 kilo. respectively. It is thus seen that whilst the loss is measurable, it is certainly not a source of error which could affect any deductions that may be made from the experiments.

The plan of the experiments.—As explained briefly in the Introduction, the transpiration ratio has been determined for (*a*) plants grown in a variety of soils in order to ascertain whether the nature of the soil had any effect on the result, and (*b*) plants grown in large jars of Pusa soil in order to ascertain the effect of the larger mass of soil. In addition to the latter, sugar-cane has been grown in 1910 in large jars (size E) in order to estimate its water requirements. In the section (*a*) four soils, namely, from Pusa, Akola, Shillong and Palur, were used in the monsoon of 1908 when maize was the only plant grown; both large and small jars were here included. In the cold weather season of 1909-10 the first three soils were again used and several varieties of crop grown; only the largest jars were employed. In the section (*b*) the same seven crops were experimented with as were grown in the preceding cold weather. The whole series may be conveniently set out in the following manner. The letters (*a*) and (*b*) indicate the sections of the work for which each crop served:—

Season.	Pusa soil.	Akola soil.	Shillong soil.	Palur soil.
Monsoon 1908 ...	Maize (*a*).	Maize (*a*).	Maize (*a*).	Maize (*a*).
Cold weather, 1909-1910	Wheat (*a* & *b*). Sarson (*a* & *b*). Linseed (*a* & *b*). Peas (*b*). Barley (*b*). Oats (*b*). Gram (*b*).	Wheat (*a*). Sarson (*a*). Linseed (*a*).	Wheat (*a*).	
February—December, 1910 ..	Sugar-cane.			

Data obtained.—The Statements Nos. I—VI set out details regarding the sizes of jars used, the quantities of soil, proportion

of moisture maintained, whether fertilizers were added or not and in what quantity, besides the weights of crops and amounts of water transpired, etc., and for information regarding these matters reference must be made to them. It will be seen that in all cases some jars of soil were unmanured, in some, "incomplete" fertilizers were used, and again in all cases some jars of soil received a "complete" fertilizer. In respect of the term "complete" manure, since the addition of potash salts to the Pusa soil has never proved an advantage, a mixture of nitrogenous and phosphatic manure is a "complete" fertilizer for this soil.

As in the previous Memoir, the number given to each plate or chart is that of the statement to which it is related.

The Nature of the Soils.—The following details regarding the several soils will be of interest.

The Pusa Soil.—Behar, where the Pusa Institute is situated, is in the Gangetic alluvium, and its soil is as free from pebbles and other stones as is the rest of that geological area. It is also of unknown depth. The Pusa soil is exceptionally fine and contains a low proportion of true clay. It is highly calcareous, containing from 30 to 40 per cent. of calcium carbonate. Of organic matter it contains as low a proportion as Indian soils in the plains so commonly do: it is very poor in readily available phosphate and the application of superphosphate in conjunction with a nitrogenous manure increases the outturn to an unusual degree: potash salts have no effect on the crop. In relation to water, our field tests have shown that it holds about 25 lbs. per cubic foot after drainage has ceased, and crops are able to utilise as much as three or four-fifths of this. Consequently heavy cold weather crops may be grown on much of this land without the assistance of rain or irrigation. Reference to the field experiments (page 245 of this Memoir) shows that some of the crops of the cold weather of 1909-10 weighed 5,000 or 6,000 lbs. of total produce per acre, whilst the rainfall was only ·22". It is indeed probable that few soils exist which hold such stores of water in a manner readily available to the crop. The following are the analytical data :—

Elutriation.		Chemical analysis.	
Mean diam. of particles mm.	Per cent.	Insoluble silicates and sand	59·05
		Ferric oxide	2·30
< ·002 ...	3·9	Alumina	3·43
·002 – ·004 ...	4·8	Calcium oxide	17·57
·004 – ·008 ...	7·7	Magnesia	·62
·008 – ·016 ...	9·4	Potash	·45
·016 – ·032 ...	40·4	Soda	·20
·032 – ·5 ...	34·4	Phosphoric acid	·10
		Sulphuric ..	·01
	100·6	Carbonic ..	14·26
		Organic matter and combined water	1·28
			99·27
		Organic carbon ...	·46
		Organic nitrogen	·07
		Available phosphoric acid	·0031
		Available potash	·005

The Akola Soil.—Akola, in the Berars, is situated in a tract of typical "Black Cotton" soil. The chief general characteristics of this soil are (*a*) its colour, this being a dark brown verging on black, (*b*) a very high content of argillaceous substance, and (*c*) a great increase of volume when wetted or corresponding decrease when dried; it usually contains one to three or more per cent. of calcium carbonate. How much water this soil contains after drainage has ceased is not known, but since for the pot-cultures of 1909-10, 40 per cent. water was maintained and this did not cause any drainage, it is certainly greater than this. On the other hand, judging by pot-culture experience at Pusa, which is, however, not very reliable for the purpose, plants cannot obtain nearly all this water, and after the moisture has fallen somewhat, water seems to move through it under the influence of surface tension only very slowly.† Owing to its highly argillaceous character, it opens out into deep fissures on drying, and it is naturally assumed that it loses much of its moisture in this way: on the other hand, after the surface 2" or 3" has dried and provided fissures are prevented, it was found in the pot-culture work to lose only about one-half as much water as the Pusa soil, even when the moisture proportions were 30 and 20 per cent. respectively. It is probable therefore that its defect as a reservoir of moisture for plants lies, not so much in

* Determined by Dyer's method.

† This is supported by experience at Orai.

the rapid loss of water to the air, though this certainly would apply to the surface 2″ or 3″, but rather to an inability to permit its great store of water to flow to the plant. The following are the analytical data :—

Elutriation.

Mean diam. of particles mm.	Per cent.
< ·002	10·1
·002 — ·004	17·1
·004 — ·008	9·6
·008 — ·016	12·7
·016 — ·032	24·4
> ·032	17·0
	90·9

Chemical analysis.

Insoluble silicates and sand	56·11
Ferric oxide	9·83
Alumina	10·08
Calcium oxide	6·59
Magnesia	2·41
Potash	·57
Soda	·23
Phosphoric acid	·08
Carbonic acid	4·18
Organic matter and combined water	9·42
	100·80
Organic carbon	·81
Organic nitrogen	·03
Available phosphoric acid	·007
Available potash	·016

The Shillong Soil.—This is a highly ferruginous soil containing much organic matter. Shillong being situated in the Khasi Hills, enjoys a cool climate; the rainfall is heavy and fairly well distributed. Consequently an accumulation of organic matter might be anticipated. It is very friable, will hold a large amount of water and drains readily, but judging by our limited experience with it at Pusa, it loses water rapidly to the atmosphere. The following are the analytical data :—

Elutriation.

Mean diam. of particles mm.	Per cent.
< ·002	3·4
·002 — ·004	4·4
·004 — ·008	5·1
·008 — ·016	8·1
·016 — ·032	19·5
> ·032	54·9
	95·4

Chemical analysis.

Insoluble silicates and sand	72·94
Ferric oxide	7·00
Alumina	9·65
Calcium oxide	·02
Magnesia	·32
Potash	·55
Phosphoric acid	·07
Organic matter and combined water	7·86
	98·22
Organic carbon	2·63
Organic nitrogen	·15
Available phosphoric acid	·0057
Available potash	·0078

The Palur Soil.—This soil exhibits no very special characteristics except that, although sandy, the elutriation figures perhaps indicate it as more sandy than it really is.

The following are the analytical data :—

Elutriation.		Chemical analysis.	
Mean diam. of particles mm.	Per cent.	Insoluble silicates and sand	90·68
		Ferric oxide	2·47
< ·002	1·7	Alumina	3·72
·002—·004 ...	3·4	Calcium oxide	·63
·004—·008	2·8	Magnesia	·34
·008—·016 ...	3·8	Potash	·19
·016—·032 ...	14·9	Soda ...	·05
> ·032 ...	71·6	Phosphoric acid	·04
		Organic matter and combined water	1·88
	98·2		
			100·00
		Organic carbon	·54
		Organic nitrogen	·054
		Available phosphoric acid	·027
		Available potash	·011

STATEMENT I.

Zea Mays (Maize), 1908.

Jar No.	Jar size.	Soil per Jar Kilos.	Water in soil per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry Crop Seed Grms.	Dry Crop Total Grms.	Water trans-pired. Kilos.	Ratio.
				Pusa Soil.						
x	A—9" diam. × 12" deep.	14	20	Blank jar		..			(7·80)	
2		14	20	*Nil* ...	8·6·08	17·9·08	Nil	31·4	11·02	446
3		14	20				Nil	31·5	12·51	397
4		14	20	N ...	8·6·08	17·9·08	Nil	30·4	14·58	480
5		14	20				·2	32·8	13·01	397
6		14	20	N, P ...	8·6·08	17·9·08	Nil	49·9	22·41	444
7		14	20				·5	65·0	27·41	422
				Akola Soil.						
50	A—9" diam. × 12" deep.	12	30	Blank jar					(3·5)	...
51		12	30	*Nil* ..	18·6·08	26·9·08	Nil	8·4	3·68	438
52		12	30				Nil	9·3	4·21	456
53		12	30	N	18·6·08	16·10·08	1·1	12·5	9·15	732
54		12	30				Nil	14·8	8·35	564
55		12	30	N, P ..	18·6·08	26·9·08	3·5	52·9	19·34	366
56		12	30				2·3	57·9	19·94	344
57		12	30	N, P, K	18·6·08	26·9·08	1·6	51·3	16·98	331
58		12	30				2·4	59·8	20·88	349
x	E—12" diam. × 24" deep.	42·5	30	Blank jar					(5·40)	...
62		42·5	30	*Nil*	4·7·08	10·10·08	3·6	33·6	18·59	553
63		42·5	30				Nil	11·9	9·57	804
64		42·5	30	N	4·7·08	10·10·08	4·5	35·2	17·29	491
65		42·5	30				6·4	46·4	26·35	568
66		42·5	30	N, P	4·7·08	10·10·08	14·4	137·8	44·27	321
67		42·5	30				21·4	120·7	37·42	310
68		42·5	30	N, P, K	4·7·08	10·10·08	7·5	103·4	39·73	385
69		42·5	30				31·4	114·1	39·79	349

STATEMENT I—(*contd.*)

Jar No.	Jar size.	Soil per Jar Kilos.	Water in soil per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop Seed Grms.	Dry crop Total Grms.	Water transpired Kilos.	
					Shillong Soil.					
59	A 9" diam. 12" deep.	12	25	Blank jar					(7·5)	
60		12	25	*Nil*	10-7-08	26-10-08	1·9	24·4	14·13	[illegible]
61		12	25				7·3	27·1	17·78	[illegible]
62		12	25	N ...	10-7-08	26-10-08	14·3	38·5	17·91	[illegible]
63		12	25				2·6	31·4	19·25	[illegible]
64		12	25	N, P	10-7-08	16-10-08	19·6	82·9	30·77	[illegible]
65		12	25				22·9	90·6	32·08	[illegible]
601	D—12" diam. 16" deep.	32	25	Blank jar					(10·0)	
602		32	25	*Nil*	9-7-08	26-10-08	20·8	86·9	45·27	[illegible]
603		32	25				33·3	96·6	39·76	[illegible]
604		32	25	N	9-7-08	26-10-08	4·1	81·8	41·05	[illegible]
605		32	25				5·3	60·0	32·37	[illegible]
606		32	25	N, P ...	9-7-08	10-10-08	113·0	236·5	70·11	[illegible]
607		32	25				112·1	239·4	66·50	[illegible]
608		32	25	N, P, K	9-7-08	10-10-08	115·1	268·3	78·40	[illegible]
609		32	25				103·1	242·4	77·51	[illegible]
					Palur Soil.					
501	C—9" diam. [illegible] deep.	32	20	Blank jar					(5·0)	
502		32	20	*Nil*	30-6-08	26-9-08	12·1	88·6	38·25	[illegible]
503		32	20				8·2	108·5	42·60	[illegible]
504		32	20	N	30-6-08	26-9-08	32·7	220·7	54·31	[illegible]
505		32	20				32·3	226·9	62·52	[illegible]
506		32	20	N, P	30-6-08	26-9-08	37·9	198·4	73·05	[illegible]
507		32	20				20·9	189·8	67·09	[illegible]
508		32	20	N, P, K	30-6-08	26-9-08	15·5	156·3	58·43	[illegible]
509		32	20				13·7	145·3	54·56	[illegible]

Note.—N = Ca (NO_3)$_2$ = ·005 grm. N ; P = Superphosphate = ·01 grm. soluble P_2O_5 ; K = K_2SO_4 = ·005 grm. K_2O per 100 grms. soil.

STATEMENT II.

TRITICUM SAT. (WHEAT) 1909-10.

Jar No.	Jar size.	Soil per Jar Kilos.	Water in soil per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop Seed Grms.	Dry crop Total Grms.	Water transpired Kilos.	[illegible]
					Pusa Soil.					
[illegible]	E—12" diam. × 22" deep.	48	20	Blank jars			...	...	(18·50)	
27		48	20	*Nil*	2-11-09	1-4-10	20·10	75·82	45·09	[illegible]
28		48	20	*Nil*	2-11-09	1-4-10	23·47	96·56	55·05	[illegible]
41		48	20	N, P	2-11-09	1-4-10	113·80	380·70	187·59	[illegible]
42		48	20	N, P	2-11-09	1-4-10	131·40	429·70	214·10	[illegible]
					Akola Soil.					
*	E—12" diam. × 22" deep.	41·6 43·2	40	Blank jars	...				(11·30)	
13		43·4	40	*Nil*	7-11-09	12-4-10	4·49	28·91	24·50	[illegible]
14		45·0	40	*Nil*	7-11-09	12-4-10	4·85	27·29	22·79	[illegible]
19		41·0	40	N, P, K	7-11-09	6-4-10	106·50	428·70	181·10	[illegible]
20		45·0	40	N, P, K	7-11-09	6-4-10	116·69	400·80	183·79	[illegible]

STATEMENT II—(*concld.*)

No.	Jar size.	Soil per Jar Kilos.	Water in soil per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry Crop Seed Grms.	Dry Crop Total Grms.	Water transpired Kilos.	Ratio.
				Shillong Soil.						
	12" diam. 24" deep.	45·0[illegible]	30	Blank jars					(16·90)	
		44·0[illegible]	30	Blank jars						
5		44·4	30	*Nil*	2-11-09	12-4-10	2·49	13·95	8·19	587
6		42·8	30	*Nil*	2-11-09	12-4-10	1·21	6·78	3·16	466
9		43·9	30	N, P, K	2-11-09	12-4-10	63·99	179·19	101·93	568
10		43·5	30	N, P, K	2-11-09	14-4-10	65·42	189·82	112·52	590

Note.—N = Ca $(NO_3)_2$ = ·005 grm. N; P = superphosphate = ·01 grm. soluble P_2O_5; K = K_2SO_4 = ·005 grm. K_2O per 100 grms. soil.

STATEMENT III.

Brassica campestris (Sarson) 1909-10.

No.	Jar size.	Soil per Jar Kilos.	Water in soil per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry Crop Seed Grms.	Dry Crop Total Grms.	Water transpired Kilos.	Ratio.
				Pusa Soil.						
	12" diam. 24" deep.	48	20	Blank jar					(13·60)	
39		48	20	*Nil*	2-11-09	26-2-10	9·74	38·10	17·95	472
40		48	20	*Nil*	2-11-09	26-2-10	9·74	37·91	18·58	490
53		48	20	N, P	2-11-09	26-2-10	85·65	266·35	101·10	392
54		48	20	N, P	2-11-09	26-2-10	86·87	267·37	100·69	377
				Akola Soil.						
	12" diam. 24" deep.	41·6	40	Blank jars ...					(8·60)	
		43·2	40	Blank jars						
15		42·2	40	*Nil*	7-11-09	7-3-10	14·68	50·89	32·05	591
16		43·1	40	*Nil* ...	7-11-09	11-3-10	9·83	38·00	23·40	616
21		42·7	40	N, P, K	7-11-09	7-3-10	88·94	275·64	127·94	464
22		43·2	40	N, P, K	7-11-09	11-3-10	79·69	282·39	139·93	495

Note.—N = Ca $(NO_3)_2$ = ·005 grm. N; P = Superphosphate = ·01 grm. soluble P_2O_5; K = K_2SO_4 = ·005 grm. K_2O per 100 grms. soil.

STATEMENT IV.

Linum usitatissimum (Linseed) 1909-10.

No.	Jar size.	Soil per Jar Kilos.	Water in soil per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry Crop Seed Grms.	Dry Crop Total Grms.	Water transpired Kilos.	Ratio.
				Pusa Soil						
	12" diam. 24" deep	48	20	Blank jar					(16·86)	
[illegible]		48	20	*Nil* ...	2-11-09	21-3-10	10·97	45·25	41·72	922
[illegible]		48	20	*Nil*	2-11-09	21-3-10	5·72	22·86	28·97	1267
[illegible]		48	20	N, P ...	2-11-09	21-3-10	36·17	135·98	92·49	680
[illegible]		48	20	N, P ...	2-11-09	21-3-10	27·66	123·25	72·31	587

STATEMENT IV—(*contd.*)

Jar No.	Jar size.	Soil per Jar Kilos.	Water in soil per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry Crop Seed Grms.	Dry Crop Total Grms.	Water transpired Kilos.	
				Akola Soil.						
	E—12" diam. 24" deep.	41·6 43·2	40	Blank jars	...	...	...	...	[illegible]	
17		43·4	40	*Nil* ...	7-11-09	27-3-10	2·47	9·61	11·8[illegible]	[illegible]
18		43·1	40	*Nil* ...	7-11-09	27-3-10	1·90	7·63	7·8[illegible]	[illegible]
23		43·4	40	N, P, K ...	7-11-09	25-3-10	26·55	88·76	70·77	[illegible]
24		45·0	40	N, P, K ...	7-11-09	25-3-10	31·30	107·47	82·87	[illegible]

Note.—N = Ca $(NO_3)_2$ = ·005 grm. N ; P = Superphosphate = ·01 grm. soluble P_2O_5; K = K_2SO_4 = ·005 grm. K_2O per 100 grms. soil.

STATEMENT V.

Other Crops in Pusa Soil 1909-10.

Jar No.	Jar size.	Soil per Jar Kilos.	Water in soil per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry Crop Seed Grms.	Dry Crop Total Grms.	Water transpired Kilos.	
				Hordeum vulg. (*Barley*).						
	E—12" diam. 24" deep.	48	20	Blank jar	...	...	...	...	(16·50	
29		48	20	*Nil*	2-11-09	17-3-10	39·76	75·54	36·66	[illegible]
30		48	20	*Nil*	2-11-09	17-3-10	29·07	71·27	29.36	[illegible]
43		48	20	N, P	2-11-09	23-3-10	125·20	342·20	157·00	[illegible]
44		48	20	N, P	2-11-09	23-3-10	146·40	382·10	172·40	[illegible]
				Avena sat. (*Oats*).						
	E—12" diam. 24" deep.	48	20	Blank jar	...	...	...	...	(16·30	
31		48	20	*Nil*	2-11-09	19-3-10	31·61	81·42	39·45	[illegible]
32		48	20	*Nil*	2-11-09	19-3-10	23·98	58·12	29·10	[illegible]
45		48	20	N, P	2-11-09	17-3-10	123·60	275·40	103·29	[illegible]
46		48	20	N, P	2-11-09	17-3-10	132·90	292·10	117·34	[illegible]
				Cicer arietinum. (*Gram*).						
	E—12" diam. 24" deep.	48	20	Blank jar	...	...	...	...	(17·7	
35		48	20	*Nil*	2-11-09	24-3-10	18·11	42·66	43·74	[illegible]
36		48	20	*Nil*	2-11-09	29-3-10	12·96	32·96	46·41	[illegible]
49		48	20	N, P	2-11-09	24-3-10	101·00	271·20	175·85	[illegible]
50		48	20	N, P	2-11-09	24-3-10	97·11	247·40	166·17	[illegible]
				Pisum sat. (*Peas*).						
	E—12" diam. 24" deep.	48	20	Blank jar	...	...	...	...	(15·20	
33		48	20	*Nil*	2-11-09	7-3-10	14·57	38·54	31·36	[illegible]
34		48	20	*Nil*	2-11-09	7-3-10	13.28	37·72	30·49	[illegible]
47		48	20	N, P	2-11-09	14-3-10	66·36	243·46	138·81	[illegible]
48		48	20	N, P	2-11-09	14-3-10	45·94	221·14	137·25	[illegible]

Note.—N = Ca $(NO_3)_2$ = ·005 grm. N : P = Superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

STATEMENT VI (a).

Sugar-cane grown in Pusa Soil 1910.

Jar No.	Size of Jar.	Soil per Jar Kilos.	Water in soil per cent.	Manures.	Date of Planting.	Date of Harvest.	Total dry matter Grms.	Water transpired Kilos.	Ratio.
55	E 12" diameter 24" deep.	About 47 kilos Pusa soil.	20	Blank jars.	8th and 9th March 1910.	9th and 10th December 1910.		(25·90)	
56			20					(20·19)	
57			20	*Nil.*			241	113·58	471
58			20				490	149·46	305
59			20	Farm manure			333	128·47	386
60			20				576	167·60	291
61			20	Farm manure and Superphosphate.			547	164·98	302
62			20				429	164·10	383
63			20	Calcium Nitrate			454	134·26	296
64			20				418	137·46	329
65			20	Calcium Nitrate and Superphosphate.			856	181·18	212
66			20				950	201·94	213
67			20	Oil cake.			562	176·15	313
68			20				556	188·85	340
69			20	Oil cake and Superphosphate.			508	184·71	364
70			20				669	208·33	311

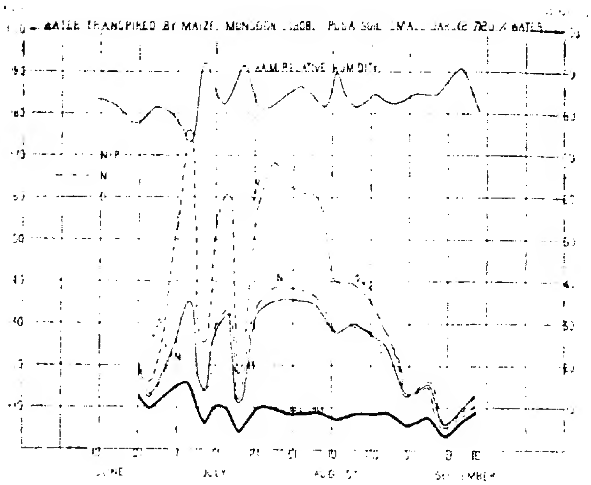
Note.—Nitrogen in manure used = ·005 parts ; P_2O_5 = ·005 parts per 100 parts soil.

STATEMENT No. VI (b).

Sugar-cane grown in Pusa Soil 1910.

Jar No.	Manures	Harvest Weight. Clean cane. Grms.	Harvest Weight. Leaves Grms.	Juice. Grms.	Juice. Sp. gr.	Juice. Total solids Brix (corr.)	Juice. Grms. sucrose per 100 Grms. juice.	Juice. Grms. invert sugar per 100 Grms. juice.
57	*Nil*	191	326	110	1·0830	20·27	18·34	·76
58		808	454	524	1·0882	21·50	20·21	·64
59	Farm manure	482	397	270	1·0854	20·78	19·66	·84
60		1,020	553	668	1·0830	20·28	18·89	·67
61	Farm manure and Superphosphate.	978	539	614	1·0892	21·47	20·73	·47
62		609	497	367	1·0893	21·47	21·02	·53
63	Calcium Nitrate	723	468	432	1·0907	21·87	21·56	·53
64		623	451	397	1·0955	22·87	22·51	·57
65	Calcium Nitrate and Superphosphate.	1,461	837	988	1·0977	23·37	22·90	·68
66		1,582	893	995	1·1003	23·97	23·10	·60
67	Oil cake	765	609	434	1·1010	24·07	22·90	·65
68		893	567	577	1·0920	22·17	21·41	·51
69	Oil-cake and Superphosphate.	686	553	422	1·0900	21·67	21·05	·58
70		977	723	593	1·0930	22·37	21·70	·47

CHART I*a*.



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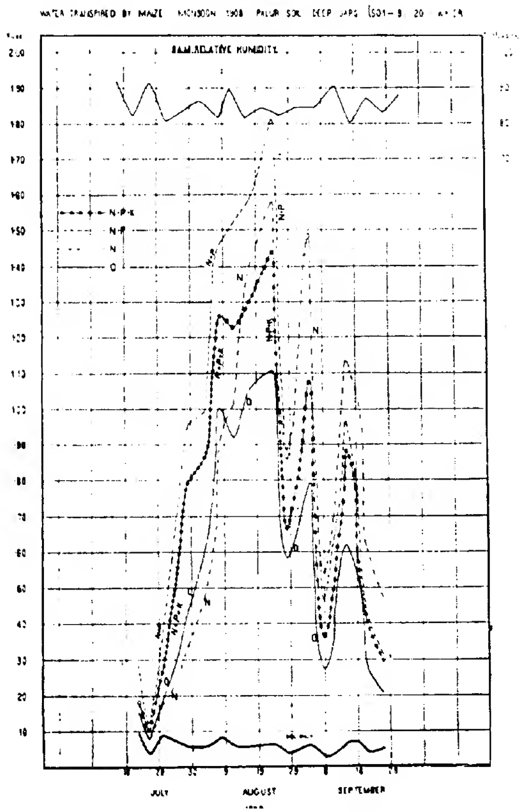


CHART 1*b*.

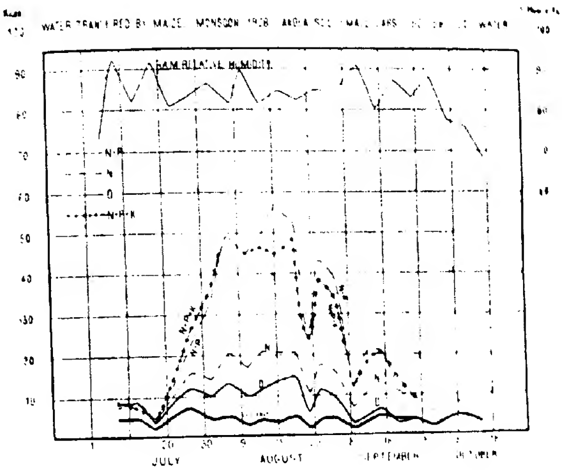


CHART 1*c*.

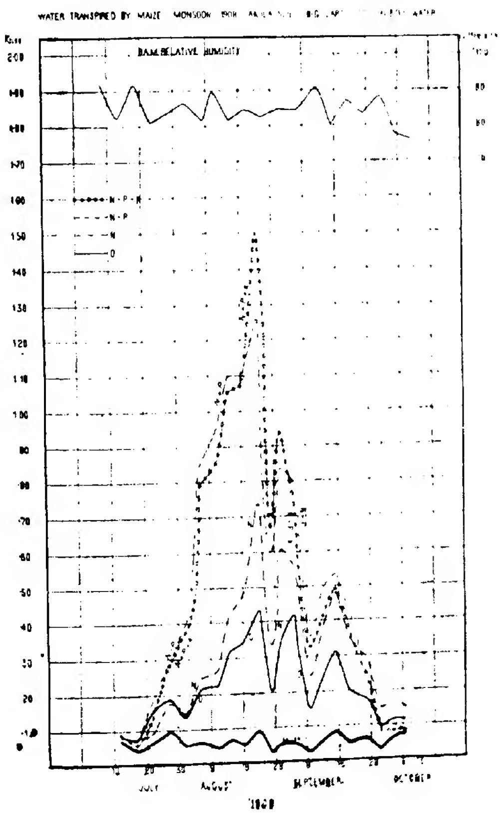


CHART I*d*.

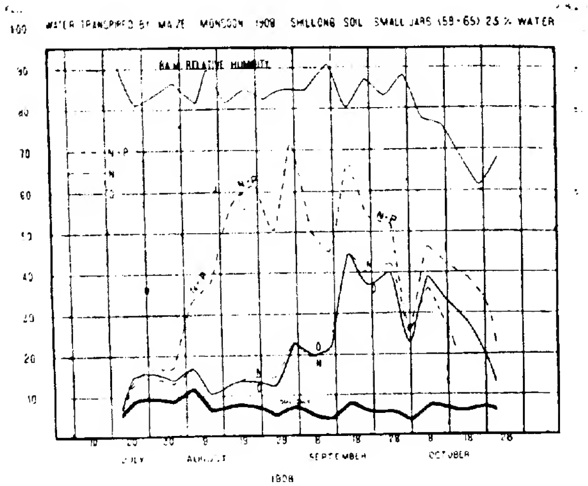


CHART I*e*.

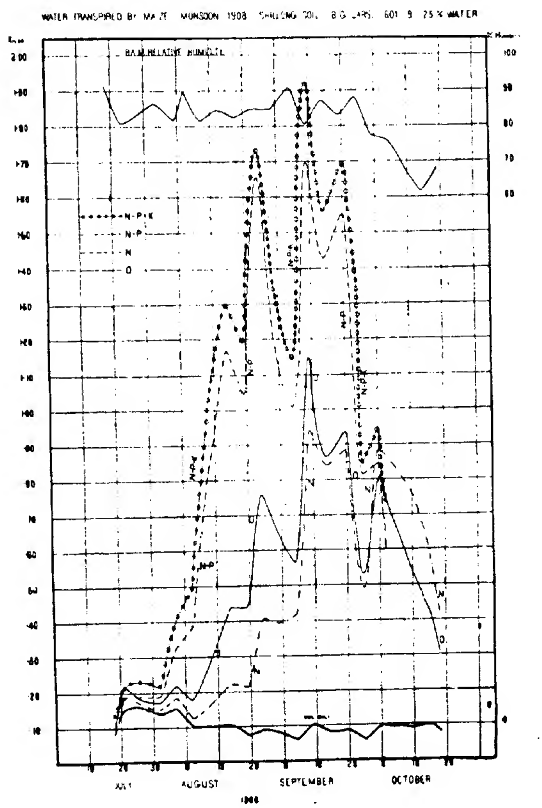


CHART IIa.

WATER TRANSPIRED BY

WHEAT—PUSA SOIL. 1909–10

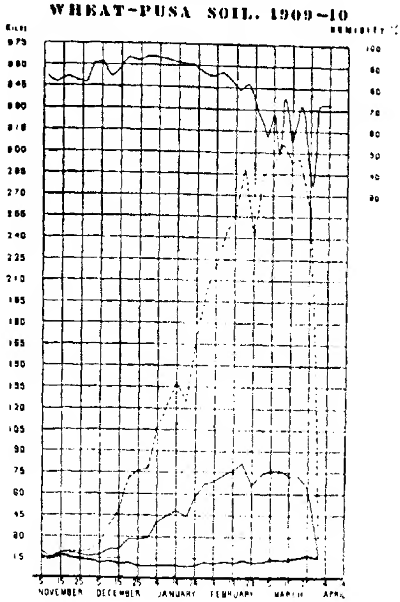


CHART IIb.

WATER TRANSPIRED BY

WHEAT—AKOLA SOIL. 1909–10

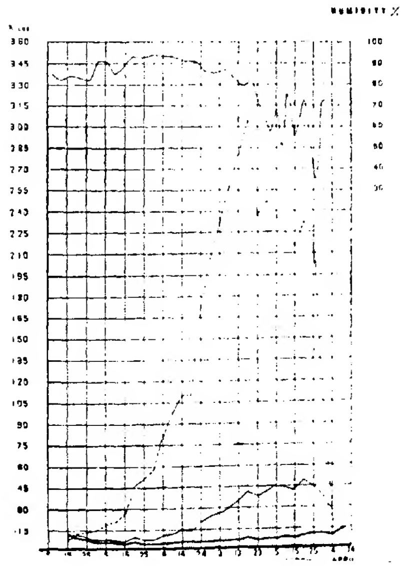


CHART IIIa.

WATER TRANSPIRED BY SARSON-PUSA SOIL. 1909-10

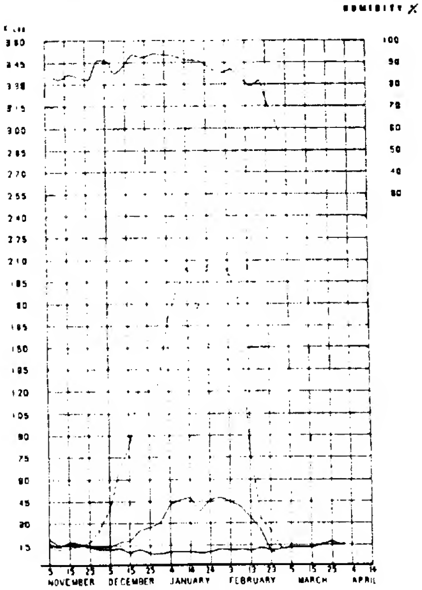


CHART IIIb.

WATER TRANSPIRED BY SARSON-AKOLA SOIL. 1909-10

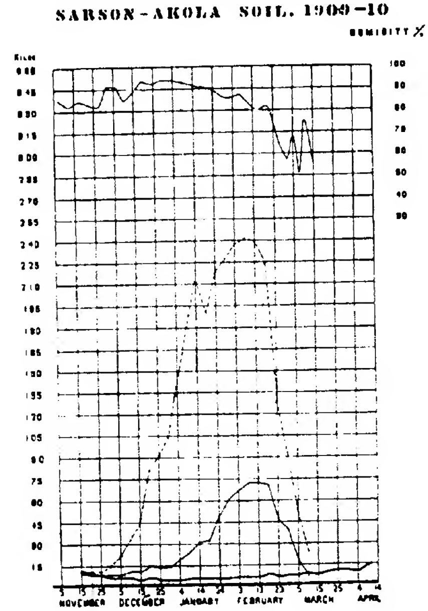


CHART IVa.

WATER TRANSPIRED BY

LINSEED-PUSA SOIL. 1909-10

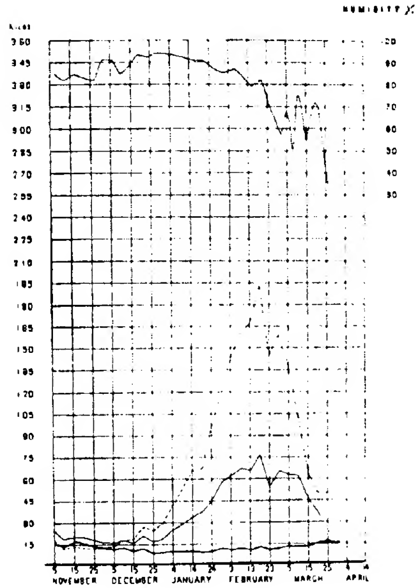


CHART IVb.

WATER TRANSPIRED BY

LINSEED-AKOLA SOIL. 1909-10

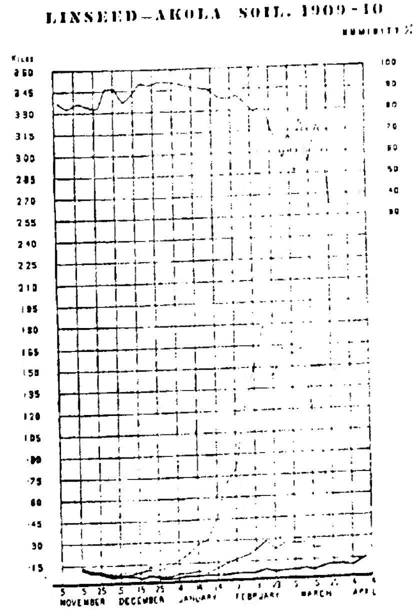


CHART V*a*.

WATER TRANSPIRED BY

BARLEY-PUSA SOIL. 1909-10

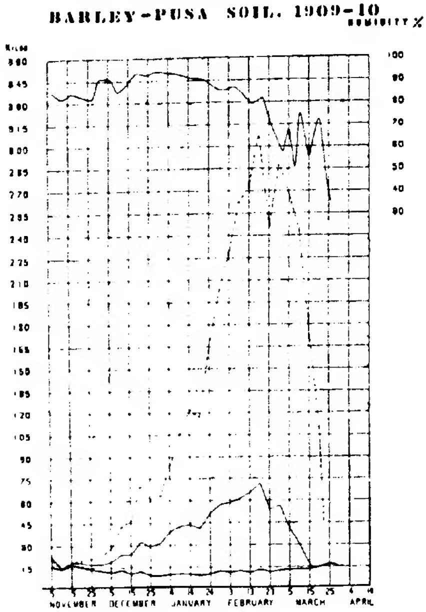


CHART V*b*.

WATER TRANSPIRED BY

OATS-PUSA SOIL. 1909-10

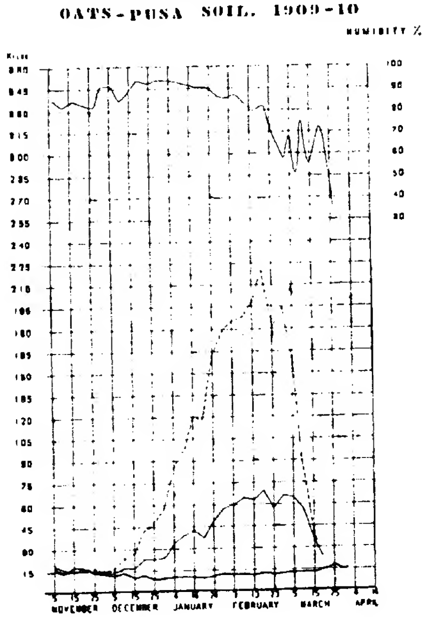


CHART V*c*.

WATER TRANSPIRED BY GRAM-PUSA SOIL. 1909-10

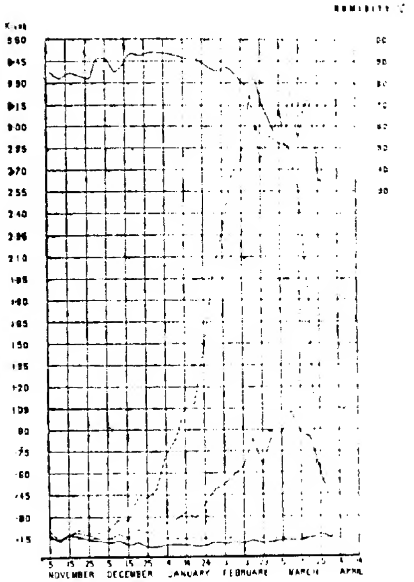


CHART V*d*.

WATER TRANSPIRED BY PEAS-PUSA SOIL. 1909-10

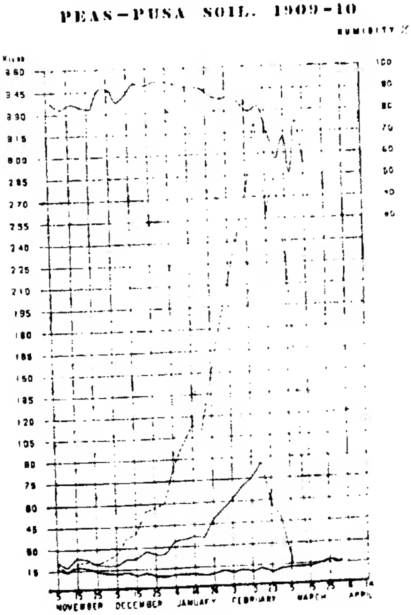


CHART IIc.

WATER TRANSPIRED BY

WHEAT-SHILLONG SOIL. 1909-10

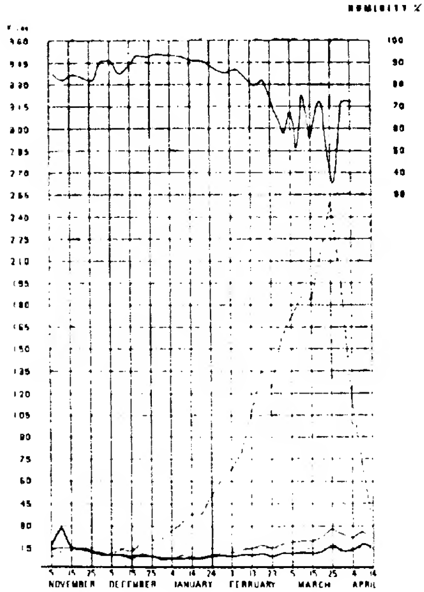
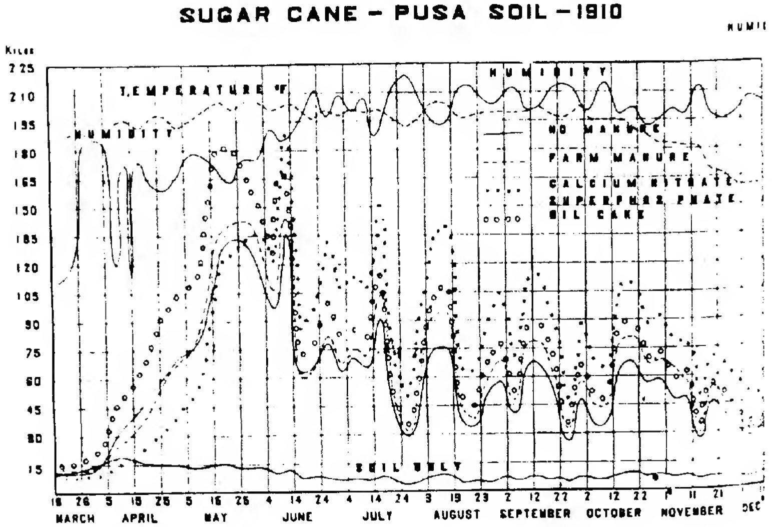


CHART VI.

WATER TRANSPIRED BY

SUGAR CANE - PUSA SOIL - 1910



Deductions.

The effect of difference of Soil.—The most complete test of the effect of difference of soil on the transpiration ratio was with maize in 1908 when it was grown in four soils and in different sized jars. The results are collected in Statement No. I, and whether the comparison is made among the small jars or the large ones, it is evident that no marked effect is traceable to the chief variant, the soil. The unmanured plants in the Akola and Shillong soils provided a somewhat greater transpiration ratio than did those in Pusa and Palur soils, but if jar No. 703 Akola soil were excluded, the differences would be only nominal: and the similar comparison among the jars of manured soils shows correspondingly small variation. The second crop used was wheat (Statement II) grown in three soils all in large jars. Here the *unmanured* Akola soil led to a higher ratio than did either of the others, but no material difference was realised among the *manured* soils. Finally an examination of the ratios obtained for Sarson (Statement III) grown in two soils and for linseed, grown in the same two soils (Statement IV) also demonstrates how small is the effect of the soil on the transpiration. In all cases the chief factors are the nature of the plant and the effect of the manure.

The effect of the larger mass of Soil.—The effect of the mass of soil on the transpiration ratio was referred to in Memoir No. 8* when attention was drawn to the lower ratio which had usually been found when large jars of soil were employed. Hence a comparison of the ratios obtained for the seven "cold weather" crops which were grown in small jars of Pusa soil in 1908-09 with those grown in the large jars of the same soil in 1909-10 are of considerable interest. The means of the duplicates are as follows :—

* P. 167 and again p. 180

Crop.	1908-9. Small Jars.		1909-10. Large Jars.	
	No fertilizer.	Complete fertilizer.	No fertilizer.	Complete fertilizer.
Wheat	865	507	582	465
Barley	675	481	448	455
Oats	629*	551	493	388
Gram	1,429	977	1,216	669
Peas	835	530	811	595
Linseed	1,092	1,000	1,094	633
Sarson	736	624	481	384

These figures demonstrate very well the liability to obtain high ratios when the plants are only grown in small jars of soil; and the effect is nearly as pronounced where fertilizers were used as where they were not. Accordingly the quantities of water estimated to be required as set out on page 182 of Memoir No. need some revision, especially for linseed and gram and possibly guar. Linseed and gram undoubtedly have a higher transpiration ratio than the other cold weather crops named (see also p. 270 of this Memoir), but not so disproportionately higher as was first estimated. In other respects these newer tests support the several deductions which were made in the previous memoir.

Effect of Phosphates.—A special reference is necessary to the results obtained with the Palur soil. This soil was selected because it was known not to require phosphatic manure. The preceding pot-culture work in relation to transpiration had shown that where the fertilizers included superphosphate the transpiration ratio was small, and the question naturally arose whether this was due simply to a stimulating effect of the manure in a general sense or whether it was referable to a specific effect of phosphates. All other soils which had been used had produced a larger plant when superphosphate was added to the soil, showing that they were deficient in available phosphates, and coinciding with this increased growth was a decreased transpiration ratio. Transpiration records obtained with such soils were of no use for the elucidation of the foregoing question. If, however, a soil were employed which, so far as plant development is concerned, did not require

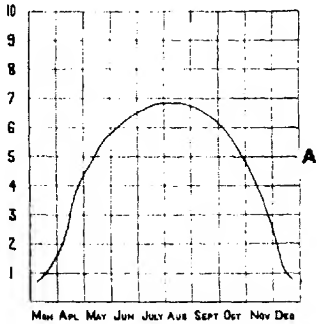
* Only one jar included; other plants unusually small.

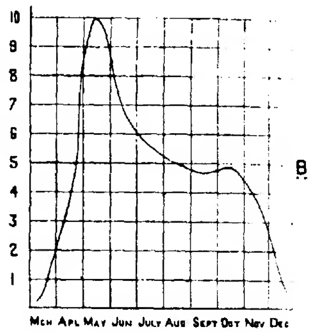
a phosphatic fertiliser, then if the superphosphate had any specific effect on transpiration, it might be expected to be demonstrated, in that without a marked increase of plant development, the transpiration ratio should be lowered. The Palur soil has fulfilled this office well, for the best plants and the lowest transpiration ratio were obtained by the use of a purely nitrogenous fertiliser, thus demonstrating that the effect of the superphosphate in the other experiments had been due purely to the deficiency in those soils of readily available phosphate and not to any specific action on transpiration by phosphates.

Sugar-cane. The sugar-cane cultures deserve a special reference in part because of the importance of the crop, in part because the course of transpiration differed somewhat from that of most crops previously experimented with

Two sets of "Ashy Mauritius" cane, one of the best types of thick cane, were planted in each of the jars early in March, all of which produced one or more shoots. In most jars either two or three canes developed well; the cane grew to a height of 9 or 10 ft. The canes were cut early in December, that is, after nine months' growth, and not only the fresh and dry weights ascertained but the juice also analysed. Reference to statement VI (*b*) gives details from which it is seen that the quality of the cane and juice left nothing to be desired. The juice was indeed some of the richest that I have ever met with. Turning next to the chart showing the daily transpiration, this includes the following curves (*i*) humidity, and temperature, a plain line and a dotted line respectively in the upper part of the chart, (*ii*) evaporation from soil only, (*iii*) four curves obtained from the cane jars. Of the fourteen jars, it was only convenient to record on the chart the curves of a small number, for the quantities of water transpired were so similar that the curves run together largely, and hence the mean daily water requirement is recorded on the chart for only the following (*a*) No manure, (*b*) Farm yard manure, (*c*) Calcium nitrate and superphosphate, (*d*) Oil-cake. The curves run together with remarkable uniformity, even small differences being present in all four. About 30 days after plant

ing, the canes shot rapidly and the maximum water requirement was reached after another 40 days. Thirty days later the requirement fell and throughout the remaining period of nearly six months the transpiration gradually fell off. It will be observed that herein lies a marked distinction. The curves for nearly all crops have been of the type (*a*) that for sugar-cane is of the type (*b*).





Although the four curves run parallel, those relating to the cane manured with oil-cake and with the artificial manure lie uniformly higher than those relating to the "Farm-manure" and "No manure" jars, which difference is largely, though not entirely, due to larger crops in the former cases. The period of maximum water requirement coincides apparently with three features: *namely*, a *combination* of (*i*) greatest heat and (*ii*) lowest humidity of the growing season, (*iii*) after the plants had commenced to grow rapidly. After the humidity rose to over 80 per cent. the water requirement fell materially. The effect of *humidity* is very clearly shown after June 15th, for with every rise of humidity there was a decrease of transpiration; with every fall an increased transpiration. The chart includes a curve of the shade temperature (......line = °F) at 8 A.M., and there is generally with every rise of humidity a fall of temperature, so that both factors act together in the same direction on the transpiration. The effect of humidity is greater than that of temperature.

Referring now to Statement No. VI (*a*) it is seen that the weights of crop produced varied considerably according to the manure used. Farm manure either alone or mixed with

superphosphate caused a moderate increase: oil-cake was more effective, and oil-cake and superphosphate more effective still. Calcium nitrate alone was about equal to farm manure, but calcium nitrate plus superphosphate produced a very much larger crop than any of the other fertilisers, in fact, it nearly trebled the yield in comparison with the unmanured plants. At the same time too much weight should not be attached to these manurial effects. It is to be recollected that both farm manure and oil-cake must undergo changes, due to bacterial action, before they become plant foods, and we know nothing about the precise bacterial conditions in this experiment. On the other hand, the value of the mixture of calcium nitrate and superphosphate is as distinctly demonstrated in these cultures as it has been regularly throughout this work.

Lastly, from Statement VI (*a*), we learn what the relative water requirement of the sugar-cane crop is. This is shown in the last column; the transpiration ratio varies from 170 for the unmanured cane down to about 200 for the cane manured with the artificials. These ratios are, on the whole, the lowest that I have met with throughout the series of experiments on transpiration, and demonstrate that, relatively to the weight of crop grown, the water requirement of sugar-cane is very small. The weight of a good cane crop is, however, very large: 30,000 lbs. of cane per acre is very common; 60,000 is in certain localities regularly obtained; add to these the weights of leaves which will be 50 per cent. more. Such crops are equivalent to something like 25,000 and 50,000 lbs. of dry matter per acre; and the equivalent in water, assuming the ratio to be 300, works out to 33″ and 66″ respectively. Such brief calculations will be sufficient to explain the chief reason for the liberal irrigation which the cane crop requires in the dry parts of India. It is also to be recollected that the transpiration ratios have been obtained in a country (Behar) which enjoys a comparatively humid climate, and since the effect of humidity on transpiration is so marked, the ratio for the drier parts of India such as the Punjab or Sind, may be higher.

PART II.

Field Experiments.

In 1907 it was decided to trace the changes which would occur in the moisture content of a soil where a crop is growing, in order (*i*) to compare such changes of concentration with those of fallow soil, and (*ii*) to try to calculate the transpiration ratio from these changes. There are probably no records of soil moisture taken throughout the root range of a crop over the whole growing period, and hence the comparison indicated under (*i*) would, in any case, be of considerable interest; and if moreover such records could be utilised to check even approximately the transpiration ratios of crops which were being obtained by the pot-culture methods, the value of the work would be very greatly increased.

It will perhaps enable the reader to appreciate the general conditions associated with the *method* which has been employed in this work if the following matters are explained :—

(*i*) The method of obtaining specimens of soil and of estimating the amount of water present in them down to a number of feet from the surface has been described in Memoir No. 6, and it will be sufficient to say here that an iron or steel cylinder 2″ diameter and 3″ or 6″ long, attached to an iron shaft, is forced by revolving the shaft handle and with the aid of a lever (see plate No. I) into the ground until it has sunk to the desired depth, *i.e.*, 3″ or 6″ respectively, and then withdrawn; if the soil is not absolutely dry or not excessively wet, the cylinder brings with it the small column of soil which is required. The cylinder is then detached from the shaft, weighed, and the soil then transferred to a suitable tray in which it is dried at about 100°C. By thus taking out successive cylinders full, specimens of the soil of consecutive depths, 3″ or 6″, are readily obtained, and thus the moisture determined in successive depths of the soil. Moreover, since the *volume* of soil removed in each cylinder is readily calculated, the amount of water present can be expressed in terms of weight per unit

volume; "pounds per cub. feet" has been adopted at Pusa. The cylinders which were previously described are cylindrical inside and slightly conical in the lower part outside; (see plate No. I), *i.e.*, they force the soil away from them and withdraw a cylinder of soil of their internal dimensions. Whilst these cylinders work perfectly well in moist soil, they do not cut into a dry soil freely, and it became necessary to devise one which would do this. The pattern adopted is shown in the plate. It consists of a plain cylinder, *i.e.*, it is cylindrical on *both* faces; it is about 1″ longer than the depth it is required to penetrate, and is 1/8″ thick. On its lower edge two tongues of the metal protrude and each of these tongues is cut into three parts, the centre one of which is then bent *inwards* slightly. When this cylinder is used, the teeth *disturb* the soil they come in contact with, and this disturbed soil passes into the cylinder; consequently the amount of soil abstracted is equal to the *outer* dimension of the tool. This tool works very well in dry soil and cuts through *kankar* (concretionary limestone) readily.

The moisture record has been maintained to a depth of 9 ft. in most of the work.

It is quite necessary to record with considerable precision exactly where each boring is made in the plot. After completing a boring the hole is filled most conveniently with dry earth; this earth will naturally abstract moisture from the soil surrounding it, and hence a subsequent test should not be made within a certain radius of a previous one; this radius works out to about 1′ 4″ in order to avoid a possible error of ·1 lb per cub. ft. In order then to be able to trace the position of boreholes, reliance has been placed on rectangular measurements from a fixed point, and two sides of the area of land comprising the plot or series of plots, which was considered much safer than indicating boreholes by any direct means such as by pegs.

(*ii*) In the first season the moisture was determined before sowing the crop, but in subsequent years this has been also done after the plant was well above ground. In order to ascertain the amount of water with as much precision as possible, it

should be determined in each plot; but when these aggregated thirteen, and since only one test (which included eighteen or specimens to be bored out and dried) could be carried out per day, it became practically impossible to test each plot at the time of sowing. In 1908 four such tests were made, each representing the moisture of three plots at sowing time, but it was decided to try to make these tests somewhat later, after the crop had commenced to grow, one in each plot. In order to do this bricks were laid between rows of plants (see plate II) on which a platform was laid over the young crop, and the soil specimens were thus obtained without injury to the crop. A further advantage lies in making the initial moisture determination at this period rather than at sowing time, inasmuch as it is only after the plant is a few inches high that it commences to transpire more than nominal amounts of water, and it is from this period rather than from date of sowing that many of the estimates of water have been made.

(*iii*) The manner of expressing the quantities of water involved needs a word of explanation. It has been mentioned that, from the water found in the soil specimens, the weight of water per unit volume of soil is readily calculated, and that this is expressed in terms of "pounds per c. ft." But whilst this mode of expressing the "concentration" of the water enables one to measure changes in that respect throughout the 9 ft. of soil in which the records have been kept, it does not enable one directly to compare quantities of water with the area of the land or weight of the crop. For this purpose it becomes necessary to calculate from the ascertained concentrations, the weight of water in the soil, say, throughout the root range of a unit area, and to express the result in terms such as lbs. or tons of water per acre x feet deep.

We must in fact adopt a *column of soil* of a specified cross section. For the purposes of the work now being described the unit adopted is a soil column 9 ft. deep and 1 sq. ft. cross section. *The depth* 9 ft. was initially selected because the shaft of the boring tool did not admit of specimens of soil being taken to a

PLATE I.

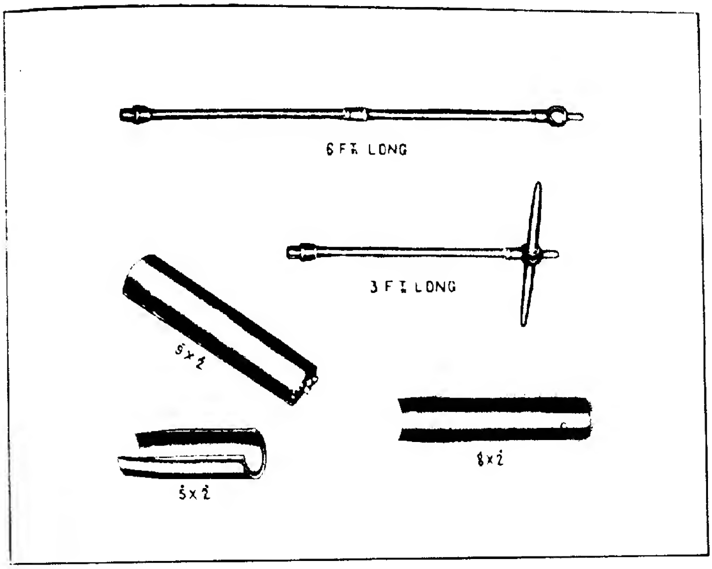


PLATE II

greater depth. It was also believed that changes of concentration of water due to plants would not extend in the soils which were selected for experiment beyond this depth; and although experience has indicated a somewhat greater depth to be affected at Cawnpore, 9 ft. has proved to be substantially sufficient. A longer shaft could readily have been provided, but the work had proceeded very far before any advantage in taking deeper lying soil specimens was observed; an advantage which would indeed have been only nominal. Also it may be mentioned that, taking these specimens and executing all the weighments in the hot weather is no light task, especially when deep borings are taken. Then, secondly, a small *unit cross section* was selected because the moisture record is obtained from either one or at most two borings of only 2″ diameter each. To quote the weight of water involved as (say) "tons per acre" would bear no relationship to the actual mass of soil experimented with. A small unit was hence advisable, and the one adopted is a very convenient one. The weight of water (pounds) in the unit column 9 ft. × 1 sq. ft. may also be converted to inches of water on the land surface if divided by 5·21, since this is the weight (pounds) of water 1″ deep × 1 sq. ft. Then, again, it became necessary to connect the weight of water in the soil column with the crop, and here also a small unit of area is very desirable. Our moisture determinations were made in only very small columns, 2″ diameter of soil, and although by making two such tests 2 or 3 ft. apart, a comparatively accurate estimate of a much larger area is obtained, it is to be recollected that these tests only yield information of the amount of water within a small area, for it is known that the quantity of water present in any field varies almost from yard to yard to such an extent that these differences may affect quite seriously the calculations which are necessary in this work. Theoretically one would like to estimate the crop grown on the actual small soil column in which the moisture is determined. Such would be obviously impossible, but sufficient has been said to explain why a quite small area of crop has been selected for weighment. It is the more necessary to go into these

details because in much agricultural work the weight of a crop from not less than at least 1/10 acre is considered necessary in order to obtain useful data. In this soil moisture work, however, had such an area been weighed, most of the crop would have been drawing its moisture supply from an area, or volume of soil, in regard to which the moisture record had but a slight connection. At the same time it is highly probable that had only (say) the crop on 1 sq. ft. been weighed, an even greater error in measurement would have occurred; for whilst one could measure fairly accurately 12" from between one row of plants to another corresponding line, the similar measurement *in* the row would have led to difficulties as to whether a certain plant should be included or not in the 12". Accordingly it was necessary to cut the crop from an area so large that such errors would become negligible, and for much of the work the crop has been cut from about 50 or 60 sq. ft. Such an area is large enough for the purpose, whilst it is not so large that the various measurements of soil moisture have not a close relationship to it. If then an imaginary column of soil be pictured 9 ft. high and 1 sq. ft. cross section with the crop on the top of it, the quantities of water which we shall deal with will be readily appreciated.

(*iv*) It will probably be at once apparent that such work as we are considering would lead to but little useful result if conducted during very wet weather. *All* additions of water at the surface are not inadmissible. For instance, not only can small rainfalls be readily accounted for, but as will be seen, successful measurements have been made where irrigation has been applied to the crop. The condition which in fact limits such additions of water is that these shall be measurable in the soil. If they are so great that drainage occurs throughout the root range and below it, then, since we have in the field no means of measuring the amount of such drainage, soil moisture records would only serve to show changes of water concentration, and these would be of little value by themselves under such conditions. Hence no attempt has been made to conduct these measurements during the monsoon period, which is usually

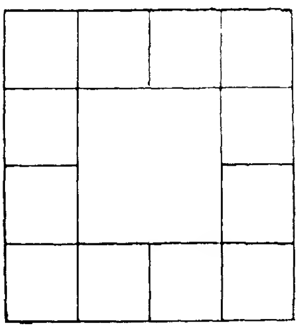
characterised by a rainfall which not only suffices for a growing crop but is in excess of this and provides water which drains away below. The experiments have on this account been necessarily restricted to the "cold weather" period when the rainfall is only nominal.

Plan of the experiments.—The first experiment was made in the cold weather of 1907-08 when oats were sown on one-half of a small plot, the other half being left fallow. The data obtained were of such interest that it was decided to extend the scope of the investigation, and for the following season plots of land were prepared (*i*) at Pusa for six crops to be grown on manured and on unmanured land, and (*ii*) at Cawnpore for six crops similarly on manured and unmanured soil. In addition, records were maintained at Cawnpore for some plots of irrigated wheat, in which measured quantities of water are used annually for this crop. Thirdly, in the season 1909-10, this work was repeated; at Pusa on two different soils; at Cawnpore on contiguous plots to those used in 1908-09.

These experiments have not been made without meeting with difficulties. The monsoon of 1908 was an exceptionally weak one, and the land at Pusa was in October of that year so dry at the surface that germination was imperfect in many fields: thus, after sowing our first selected plots, these had to be abandoned and others of a more clayey character substituted. Here germination was good on some plots and sufficiently so on the others to yield a uniform, if only a moderate crop. At Cawnpore in that season, likewise after a weak monsoon, the weights of crops were small; in such cases the effect of the experimental error is necessarily magnified and for this reason the whole unirrigated series was discarded. On the other hand, the irrigated wheat grew naturally to great perfection, and to the satisfaction of Mr. Burt and myself it was found that the moisture record could trace the depth to which the irrigation water descended into the soil. Moreover an examination of the data obtained, proved perfectly serviceable in accounting for the irrigation water and connecting the total decrease of water in the soil with the crop.

In 1909 it was decided to repeat the experiment on two classes of land at Pusa, the one a stiff clay and the other a lighter soil. But the monsoon was so unusually heavy that both these fields were too wet at autumn sowing time to admit of their use, for it was feared that drainage had not then ceased in the sub-soil which would have necessarily interfered with the record. Accordingly two other sets of plots had to be selected, and of these one was a lighter class of land than that utilised in 1908-09, whilst the other was in still lighter land. Germination and subsequent growth were all that could be desired, but rats got into both sets of plots when the crops were at their best and the whole of those on the lighter land had to be abandoned ; of those on the somewhat heavier soil (the one first mentioned above), portions of five were intact at harvest and these have yielded useful data. At Cawnpore the yields of *unirrigated* crops were again small, and it is intended to repeat this series : the irrigated wheat crop was, as previously, a very good one and again yielded valuable information.

The procedure adopted may now be concisely stated. The land selected is left fallow during the monsoon, and is thus at the end of October in the most favourable condition as regards moisture for the "cold weather" crops which are sown at this period. The cultivation should be the very best and most uniform possible. The plots are then marked out. The accompanying woodcut represents those at Pusa in 1909-10 and the others were similar. Determinations of soil moisture at one or two points are now made so as to form an estimate of what this is at sowing time, though, as has been explained, another and more complete test is taken at a later date for the "initial" moisture. When sowing, lines to receive the seeds, of suitable depth and distance apart, are opened in the plot and into each a



weighed quantity of seed is dibbled by hand with as great uniformity as possible, the aim being to have the plants distributed so evenly that anything in the nature of "bunches" of plants here and there is avoided. For the same reason cultivation of such plots with cattle is not advisable, for it is almost impossible to avoid adventitious manuring by them. After the plant is some few inches high, a determination of moisture is made in the manner already described (p. 236) at a point in each plot which appears likely to prove the most *uniform* (not necessarily the heaviest). Weeds are constantly removed so long as this can be done without injury. The crop is then left to develop and ripen off. At harvest about 50 sq. ft. of the most uniform part of the crop, and which should include in its area the site of the initial moisture determination, is cut, air-dried, weighed, threshed, and moisture determinations made in the several parts so as to be able to compute the weight of dry matter in the whole. Moisture determinations are also made within the harvested area, and since all crops do not mature at the same time, there is now rather more time available, and the moisture is determined at *two* points within the area : the one is taken between two rows of plants, the other exactly where a plant grew. It is the more necessary to duplicate the estimation of soil moisture at harvest because, whilst at sowing time the moisture is very evenly distributed throughout the small area involved, at harvest the uniformity of the remaining moisture will depend largely on the uniformity of the crop and there is necessarily more *liability* to variation in its distribution. Again a month or six weeks after harvest a further estimate of the moisture has been taken in a number of the plots in order to ascertain what changes take place in its quantity. Periodically during the season determinations of the moisture in the fallow plot are also made.

The rainfall of the several seasons at the two agricultural stations will be of interest, and is here stated. It is seen that at both stations the rainfall during the growing period was quite small, and that the crops had to depend almost entirely on the

soil moisture or, as at Cawnpore, on this plus irrigation for their supply of water.

STATEMENT No. VII.

Pusa. 1907-08.		Pusa. 1908-09.		Pusa. 1909-10.		Cawnpore. 1908-09.		Cawnpore. 1909-10.	
	In.		In.		In.		In.		In.
Jan. 12 ...	·44	Dec. 25	·04	Dec. 21	·12	Jan. 4	·08	Dec. 25	·11
,, 31 ..	·03	Jan. 18	·06	Jan. 18	·01	,, 11 .	·01	,, 26	1·64
Feb. 1 ..	·54	,, 28	·05	Feb 18	·02	,, 14	·11	Jany. 2	·06
,, 2 ..	·84	Feb. 17	·01	Mar. 4	·01	Feb., 24 ...	·05		
,, 3	·01	,, 21 ...	·16	,, 10	·06	April 20 .	·52		
,, 6 ...	·01	,, 24	·05	April 29	·13	,, 21 ..	·63		
,, 28	·11	,, 25 ..	·01	,, 30 .	·01	,, 22 ...	·19		
,, 29 ...	·76	April 13	·07			,, 23	·88		
Mar. 1 ...	·10	,, 15	·38						
,, 12 ...	·005	,, 18	1·15						
May 7 ..	·53	,, 19	·71						
		,, 24	·01						
		,, 25	·15						
		,, 26	·05						
		,, 28 ...	·01						
		,, 29	·91						

Rainfall for each crop.

Crop.	Pusa. 1907-08.	Pusa. 1908-09.	Pusa. 1909-10.	Cawnpore. 1908-09.	Cawnpore. 1909-10.
	Inch.	Inch.	Inch.	Inch.	Inch.
Oats	2·74	·38	·22		
Wheat		·38	·22	·25	1·81
Barley		·38			
Peas		·38			
Linseed ...		·38	·22		
Mustard ...	...	·32	·16		

Discussion of the data obtained.

Change of concentration of water.—The data relating to the three years' work are set out in Statements Nos. VIII to XX and in charts which are numbered VIII and XIII to XVIII This numbering of the charts has been adopted for simplicity of reference: the chart number corresponds with that of the statement from which it is derived.

The Experiments at Pusa.—Directing attention firstly to the data relating to the oat crop grown at Pusa in 1907-08 (State-

ment VIII and Chart No. VIII) it will be seen that in the *fallow* soil the water decreased to a greater degree in the stratum 1′ 9″ to 3′ 0″ than in the soil *above* it. This feature is quite characteristic of the soil of this part of the field and was observed also in the previous year. The soil is much more sandy in the third and part of the fourth foot than in the first two feet; below 4′ 0″ the soil is much more clayey. So likewise where the oat crop grew, there is a distinctly greater decrease of water content in the more sandy stratum than just above it. Then, secondly, there is a considerably greater decrease of moisture, both in the fallow soil, as also where the oats grew, in the first five feet than below this depth; the effect of the oat crop being of the two much more pronounced. Thirdly, whilst in the fallow soil there is a decrease down to about 7 ft.: this decrease extends where the oats grew to 9 ft. Now these features are very generally brought out by the data relating to the several crops grown in the two subsequent seasons, and variations among themselves depend on three factors, which are (*i*) the nature of the soil, (*ii*) the nature of the crop, and (*iii*) the weight of the latter. Of these the last has exerted generally the greatest influence, though the nature of the crop is nearly as effective. It will also be observed that the crops of 1908-09 caused a marked decrease down to about 7′ or 7′ 6″, those of 1909-10 down to 7′ 6″ or 8′ 0″, that is, rather deeper, though the difference is not great. The soils are different only in degree, that employed in 1908-09 being a stiffer soil than that of 1909-10; the amount of water present per unit column was, in the former, at sowing time considerably less than in the latter. It will be recollected that this is readily accounted for by the difference of the preceding monsoons, the rainfall of 1908 having been about one-half the normal, that of 1909 about twice the normal. Hence the question naturally occurs whether the crops in 1908-09 had not to take water from a greater depth in that soil than they would have done, when, after a normal monsoon, the soil would have contained more water: the corresponding question in regard to the experiments of 1909-10 hardly arises, because although the monsoon of 1909

had been so heavy, drainage had ceased in the first 9 ft. before sowing time, and this soil would have contained at sowing time after an ordinary monsoon rainfall as much as it did on the occasion of the experiments. Another feature which is regularly present is that there was but little decrease of concentration of water at 9 ft. in any of the experiments.

The Experiments at Cawnpore. The character of the soil.— The Cawnpore soil differs chemically from that at Pusa only in possessing an ordinary proportion of lime. Otherwise it consists of very fine earth, but is probably somewhat more clayey. In this land irregular beds occur containing nodules of concretionary limestone (*kankar*). The effect of dry weather on this soil when fallow is illustrated by the Chart No. XXV from which it is seen that it dries much more at the surface than the Pusa soil does, but that the drying effect does not extend nearly so deep. It has been mentioned that unirrigated crops do badly in this soil in the absence of rain, but with moderate irrigation they do well.

The data relating to these irrigation experiments, *vide* Statements XIX, XX, exhibit the same general features as those at Pusa, but here the decrease of water concentration is perceptible to even a greater depth and the test down to 9′ 0″ does not exhibit quite the whole extent of the decrease where the crop grew.

STATEMENT No. VIII.

OATS, PUSA, 1907-8.

Exhibiting the amount of water present in the soil (a) where fallow, (b) where Oat crop was grown, 1907-8, pounds per cub. ft.

Depth, ft.	FALLOW LAND. Initial moisture, 8th Nov. 1907.	FALLOW LAND. 31st March 1908.	FALLOW LAND. 4th May 1908.	OAT LAND. Harvest, 31st March 1908.	OAT LAND. 6th May 1908.	OAT LAND. 22nd May 1908.
0 – ¼	14·6	6·8	4·5	·5	·5	·7
¼ – ½		11·0	7·8	1·8	·7	1·5
½ – ¾	14·4	10·9	8·9	2·6	1·7	2·8
¾ – 1		11·7	10·6	3·8	3·1	4·2
1 – 1¼	13·1	11·8	8·0	4·0	4·2	4·2
1¼ – 1½		11·7	9·7	4·3	4·3	4·6
1½ – 1¾	11·6	11·3	10·5	3·9	3·4	3·8
1¾ – 2		8·6	8·9	3·0	3·0	3·0
2 – 2½	12·4	7·3	7·4	2·3	2·3	3·2
2½ – 3	15·9	10·3	9·7	2·9	3·5	4·5
3 – 3½	18·9	12·5	11·7	3·8	5·6	5·7
3½ – 4	18·3	12·2	9·4	4·3	7·0	5·8
4 – 4½	19·5	14·6	11·8	6·6	10·8	14·3
4½ – 5	23·0	18·8	20·0	11·3	16·7	14·3
5 – 5½	23·4	20·0	19·8	15·7	16·9	18·6
5½ – 6	24·0					
6 – 6½	24·3	24·2	23·4	18·4	20·0	21·4
6½ – 7	24·7					
7 – 7½	24·9	25·8	25·3	23·3	24·1	23·6
7½ – 8	25·1					
8 – 8½	25·4	26·8	25·5	26·5	25·8	24·7
8½ – 9	26·5					

Dry matter per sq. ft. ... ·186 lbs.

LBS. WATER IN UNIT COLUMNS.

Initial ...	180·0
Rain = 2·8″ ...	14·8
	194·8
Direct evaporation ...	14·0
Remaining at harvest ...	104·3
Transpired ...	76·5
	194·8

Ratio $\frac{76·5}{·186}$ 411

STATEMENT No. IX.

WHEAT, PUSA, 1908-09.

Depth ft.	Pounds of Water in Soil per Cub. Ft. — Manured — Initial, 11th December 1908.	Harvest, 30th March 1909.
0 – ½	12·9	1·9
½ – 1	18·2	4·9
1 – 1½	18·7	6·7
1½ – 2	20·8	8·9
2 – 2½	18·4	10·0
2½ – 3	21·3	13·3
3 – 3½	15·2	9·8
3½ – 4	19·7	14·5
4 – 4½	18·3	10·7
4½ – 5	16·6	11·4
5 – 5½	16·0	12·2
5½ – 6	15·3	12·7
6 – 6½	13·7	11·4
6½ – 7	12·1	8·2
7 – 7½	15·5	12·8
7½ – 8	18·9	18·6
8 – 8½	20·4	19·9
8½ – 9	20·4	20·3

Sown		November 5th, 1908.
Harvested		March 30th, 1909.
Area of crop which was weighed		52·2 sq. ft.
Weight of dry matter	Seed	1·86 lbs.
	Straw, &c.	3·32 lbs.
	Total ...	5·18 lbs.
Dry matter per sq. ft.		·099 lbs.

LBS. WATER IN UNIT COLUMN.

Initial	156·2
Rain = ·38"	2·0
	158·2
Direct evaporation	11·5
Remaining at harvest	105·6
Transpired	41·1
	158·2

Ratio ... $\frac{41·1}{·099} = 415$

STATEMENT No. X.

Barley, Pusa, 1908-09.

Pounds of Water in Soil per Cub. Ft.

Depth ft.	Manured. Initial, 12-12-08.	Manured. Harvest, 21-3-09.	Unmanured. Initial, 18-12-08.	Unmanured. Harvest, 27-3-09.
0 – ½	9·7	1·6	8·5	1·2
½ – 1	16·8	5·2	14·3	4·1
1 – 1½	17·2	7·2	16·4	6·5
1½ – 2	19·2	9·0	18·4	8·0
2 – 2½	19·8	10·4	20·2	10·6
2½ – 3	22·5	13·7	20·5	15·1
3 – 3½	19·1	12·5	21·9	15·5
3½ – 4	16·0	10·8	22·1	15·2
4 – 4½	20·3	11·1	19·3	13·8
4½ – 5	13·4	12·6	18·5	12·1
5 – 5½	13·9	11·4	17·0	11·0
5½ – 6	11·3	12·0	15·5	11·5
6 – 6½	13·1	11·9	13·6	10·5
6½ – 7	12·0	10·6	11·8	10·6
7 – 7½	15·1	11·2	17·1	10·5
7½ – 8	18·3	17·2	22·4	18·2
8 – 8½	20·7	19·3	22·3	19·1
8½ – 9	20·2	20·2	21·1	20·6

		Manured	Unmanured
Sown	..	November 3rd, 1908	November 3rd, 1908.
Harvested	..	March 21st, 1909 ...	March 27th, 1909.
Area of crop which was weighed		50·75 sq. ft.	32·6 sq. ft.
Weight of dry matter	Seed	2·93 lbs.	1·62 lbs.
	Straw, &c.	2·67 lbs.	1·80 lbs.
	Total ..	5·60 lbs.	3·42 lbs.
Dry matter per sq. ft.	..	·11 lbs.	·105 lbs.

Lbs. water in unit column.

	Manured	Unmanured
Initial	150·9	161·9
Rain = ·38"	2·0	2·0
	152·9	163·9
Direct evaporation	11·5	11·5
Remaining at harvest ..	103·9	107·2
Transpired	37·5	45·2
	152·9	163·9
Ratio	$\frac{37·5}{·110} = 341$	$\frac{45·2}{·105} = 430$

STATEMENT No. XI.

Oats, Pusa. 1908-9.

Pounds of Water in Soil per Cub. Ft.

Depth ft.	Manured.		Unmanured.	
	Initial, 10-12-08.	Harvest, 10-3-09.	Initial, 10-12-08.	Harvest, 11-3-09.
0 – ½	12·1	2·2	8·5	1·9
½ – 1	16·3	4·7	14·3	6·0
1 – 1½	16·5	5·9	16·5	7·1
1½ – 2	20·8	7·9	18·4	10·7
2 – 2½	19·5	13·8	20·2	9·2
2½ – 3	18·2	11·3	20·5	17·1
3 – 3½	18·4	13·0	24·9	17·2
3½ – 4	16·0	14·9	22·1	13·6
4 – 4½	15·5	8·8	19·3	14·7
4½ – 5	19·4	17·8	18·5	13·2
5 – 5½	17·7	13·8	17·0	11·8
5½ – 6	16·2	14·7	15·5	12·0
6 – 6½	17·1	11·5	13·6	12·2
6½ – 7	18·0	10·2	11·8	10·8
7 – 7½	19·0	17·6	17·1	15·1
7½ – 8	20·1	20·5	22·4	19·7
8 – 8½	19·8	19·9	22·3	18·8
8½ – 9	20·4	22·2	21·1	21·1

		Manured	Unmanured
Sown		November 3rd, 1908.	November 3rd, 1908.
Harvested		March 10th, 1909.	March 11th, 1909.
Area of crop which was weighed ...		55·8 sq. ft.	66·64 sq. ft.
Weight of dry matter ..	grain ...	3·57 lbs.	3·35 lbs.
	straw, &c. ..	5·14 lbs.	3·95 lbs.
	Total	8·71 lbs.	7·30 lbs.
Dry matter per sq. ft. ...		·156 lbs.	·110

Lbs. Water in Unit Column.

	Manured	Unmanured
Initial	160·5	162·0
Rain = ·38″	2·0	2·0
	162·5	164·0
Direct evaporation	11·5	11·5
Remaining at harvest	115·3	116·1
Transpired	35·7	36·4
	162·5	164·0
Ratio	$\frac{35·7}{·156} = 230$	$\frac{36·4}{·110} = 331$

STATEMENT No. XII.

Linseed, Pusa, 1908-09.

Pounds of Water in Soil per Cub. Ft.

Depth, ft.	Manured. Initial, 13-12-08.	Manured. Harvest, 16-3-09.	Unmanured. Initial, 15-12-08.	Unmanured. Harvest, 17-3-09.
0 – ½	15·4	2·7	12·6	2·8
½ – 1	17·8	6·0	15·7	6·7
1 – 1½	19·7	6·1	17·3	7·1
1½ – 2	19·9	6·8	17·9	7·5
2 – 2½	20·1	8·0	18·0	9·4
2½ – 3	19·8	8·0	21·4	11·1
3 – 3½	18·4	9·9	21·0	10·3
3½ – 4	22·7	13·0	16·1	9·5
4 – 4½	15·9	10·7	15·1	6·9
4½ – 5	16·3	12·7	16·8	12·3
5 – 5½	17·0	12·8	16·7	12·6
5½ – 6	17·7	13·5	16·6	12·2
6 – 6½	17·9	13·3	15·1	11·4
6½ – 7	18·2	13·3	13·6	11·6
7 – 7½	19·3	18·2	17·0	19·1
7½ – 8	20·5	20·4	20·5	19·8
8 – 8½	21·0	19·5	21·4	20·4
8½ – 9	19·6	20·3	19·9	21·5

	Manured	Unmanured
Sown ...	November 3rd, 1908.	November 3rd, 1908.
Harvested	March 16th, 1909.	March 17th, 1909.
Area of crop which was weighed ...	... 51·3 sq. ft.	48·12 sq. ft.
Weight of dry matter { Grain	... 1·26 lbs.	1·02 lbs.
Weight of dry matter { Straw	2·39 lbs.	1·82 lbs.
Total	... 3·65 lbs.	2·84 lbs.
Dry matter per sq. ft.	·071 lbs.	·059 lbs.

Lbs. Water in Unit Column.

	Manured	Unmanured
Initial ...	... 168·6	156·3
Rain – ·38″ ...	2·0	2·0
	170·6	158·3
Direct evaporation	... 11·5	11·5
Remaining at harvest	... 108·1	105·9
Transpired ...	... 51·0	40·9
	170·6	158·3
Ratio ..	$\frac{51·0}{·071} = 718$	$\frac{40·9}{·059} = 693$

STATEMENT No. XIII.

Mustard, Pusa, 1908-9.

Depth, ft.	Pounds of Water in Soil per Cub. Ft. — Manured. Initial, 8-12-08.	Manured. Harvest, 22-2-09.	16-4-09.	Unmanured. Initial, 14-12-08.	Unmanured. Harvest, 2-3-09.
0 — ½	15·5	6·7	5·4	12·9	4·3
½ — 1	18·6	10·2	9·6	14·7	7·3
1 — 1½	20·5	11·9	11·0	17·6	8·5
1½ — 2	20·5	11·0	8·4	20·3	10·1
2 — 2½	21·1	13·9	16·0	19·7	12·0
2½ — 3	18·6	9·9	9·0	22·7	12·4
3 — 3½	21·3	12·2	12·0	20·6	13·8
3½ — 4	21·3	12·7	10·0	20·9	13·5
4 — 4½	17·4	10·9	13·0	17·1	12·9
4½ — 5	16·7	11·3	14·0	14·6	10·3
5 — 5½	18·1	16·0	14·0	16·1	13·9
5½ — 6	19·5	15·6	15·0	17·7	13·5
6 — 6½	19·6	13·1	11·8	16·7	14·6
6½ — 7	18·5	12·8	13·2	15·7	12·5
7 — 7½	20·0	20·1	17·8	18·2	18·2
7½ — 8	21·6	20·9	18·8	20·7	19·8
8 — 8½	21·1	21·7	21·6	21·2	20·0
8½ — 9	19·6	21·1	19·6	19·9	19·9

		Manured.	Unmanured.
Sown		November 3rd, 1908.	November 3rd, 1908.
Harvested		February 22nd, 1909.	March 2nd, 1909.
Area of crop which was weighed		... 147·5 sq. ft.	130 sq. ft.
Weight of dry matter	Seed ...	6·66 lbs.	3·67 lbs.
	Pods ..	6·72 ,,	3·85 ,,
	Straw ...	5·09 ,,	3·00 ,,
	Fallen leaves .	2·97 ,,	·34 ,,
	Total ..	21·44 ,,	10·86 ,,
Dry matter per sq. ft.		·145 lbs.	·0836 lbs.

Lbs. water in unit column.

Initial	174·4	163·6
Rain : ·32"	1·7	1·7
	176·1	165·3
Direct evaporation ..	7·	7·0
Remaining at harvest	126·0	118·7
Transpired	43·1	39·6
	176·1	165·3
Ratio	$\frac{43·1}{·145}$ = 298	$\frac{39·6}{·084}$ = 471

STATEMENT No. XIV.

Peas, Pusa, 1908-09.

Depth ft.	Pounds of Water in Soil per Cub. Ft.				
	Manured.			Unmanured.	
	Initial, 9-12-08.	Harvest, 7-3-09.	5-5-09.	Initial, 17-12-08.	Harvest, 4-3-09.
0 — ½	15·9	4·1	8·6	11·0	3·6
½—1	17·3	9·0	11·6	14·4	8·3
1 —1½	19·7	11·6	13·0	18·7	12·0
1½—2	22·3	10·0	14·2	21·3	14·6
2 —2½	20·2	16·0	15·8	17·1	18·9
2½—3	19·7	11·3	13·2	21·6	20·4
3 —3½	20·1	13·4	11·6	21·2	17·2
3½—4	21·2	15·4	15·0	20·3	15·8
4 —4½	15·2	11·6	10·2	19·2	14·4
4½—5	20·5	16·7	16·8	15·6	13·2
5 —5½	19·4	16·3	13·2	15·6	13·4
5½—6	18·3	12·5	13·0	15·6	11·5
6 —6½	17·6	13·7	10·2	14·6	11·0
6½—7	17·0	10·5	9·8	13·6	11·2
7 —7½	19·3	19·4	17·4	17·0	15·4
7½—8	21·7	20·6	20·4	20·5	20·0
8 —8½	22·8	20·7	21·0	22·5	20·4
8½—9	19·6	20·8	19·8	19·9	21·4

Sown	November 3rd, 1908.	November 3rd, 1908.
Harvested	March 7th, 1909.	March 4th, 1909.
Area of crop which was weighed ...	143 sq. ft.	153·5 sq. ft.
Weight of dry matter { Straw, pods, &c	8·23 lbs.	6·35 lbs.
{ Grain	3·03 ,,	4·03 ,,
Total	11·26 ,,	10·38 ,,
Dry matter per sq. ft.	·0787 ,,	·0678 ,,

Lbs. water in unit column.

Initial	173·9		159·8	
Rain = ·38" ...	2·0		2·0	
	175·9		161·8	
Direct evaporation ...	9·2		9·2	
Remaining at harvest	126·8		131·3	
Transpired	39·9		21·3	
	175·9		161·8	
Ratio	39·9 / ·079	= 505	21·3 / ·068	314

STATEMENT No. XV.

Wheat, Pusa, 1909-10.

Pounds of Water in Soil per Cub. Ft.

Depth ft.	Manured.			Unmanured.		
	Initial, 14-11-09.	Harvest, 23-3-10.	23-4-10.	Initial, 10-11-09.	Harvest, 28-3-10.	28-4-10.
0 – ½	14·2	1·6	1·2	12·6	4·3	3·5
½ – 1	16·5	6·0	7·1	13·4	8·5	8·1
1 – 1½	16·2	6·8	6·8	14·6	13·8	6·3
1½ – 2	16·9	8·7	10·0	14·1	12·9	9·1
2 – 2½	16·9	7·9	8·0	16·6	8·8	8·8
2½ – 3	17·6	7·6	8·1	19·7	9·6	8·8
3 – 3½	18·7	9·0	8·7	19·9	9·1	8·9
3½ – 4	21·8	9·1	9·1	20·8	11·9	11·0
4 – 4½	23·2	10·0	8·6	20·6	12·4	10·6
4½ – 5	23·1	11·8	10·7	21·0	14·4	13·7
5 – 5½	24·4	16·0	15·3	24·6	13·3	11·9
5½ – 6	26·3	15·1	13·6	21·5	14·8	13·4
6 – 6½	23·8	18·7	18·9	23·4	20·7	20·2
6½ – 7	23·5	21·2	22·6	22·5	23·2	22·8
7 – 7½	22·4	21·2	22·7	25·1	22·8	24·2
7½ – 8	24·8	22·6	24·7	25·4	24·8	25·6
8 – 8½	25·0	23·3	24·5	24·6	23·9	22·4
8½ – 9	25·9	25·3	25·8	24·9	25·9	24·9

Sown	November 1st, 1909.	November 1st, 1909.
Harvested	March 23rd, 1910.	March 28th, 1910.
Area of crop which was weighed ..	60·0 sq. ft.	54·0 sq. ft.
Weight of dry matter: seed	3·03 lbs.	1·83 lbs.
straw	5·53 ,,	3·73 ,,
chaff ...	1·66 ,,	·88 ,,
Total ..	10·22 ,,	6·44 ,,
Dry matter per sq. ft.	·17 ,,	·12 ,,

Lbs. water in unit column.

Initial	190·6	182·6
Rain ·22″	1·1	1·1
	191·7	183·7
Direct evaporation	17·7	17·7
Remaining at harvest	120·9	137·5
Transpired	53·1	28·5
	191·7	183·7
Ratio	$\frac{53·1}{·170}$ = 313	$\frac{28·5}{·120}$ = 237

STATEMENT No. XVI.

OATS, PUSA, 1909-10.

Depth ft.	Pounds of Water in Soil per cub. ft. — Manured. Initial, 17-11-09.	Harvest, 14-3-10.	14-4-10.
0 – ½	12·8	1·4	1·6
½ – 1	13·8	3·3	5·6
1 – 1½	13·1	5·2	6·4
1½ – 2	17·3	8·0	8·9
2 – 2½	17·7	9·7	11·0
2½ – 3	16·8	8·4	9·1
3 – 3½	19·5	9·8	9·8
3½ – 4	21·0	8·9	8·8
4 – 4½	19·3	9·1	8·8
4½ – 5	23·7	15·3	15·4
5 – 5½	25·2	12·3	11·0
5½ – 6	24·2	13·7	12·4
6 – 6½	23·7	17·5	16·9
6½ – 7	23·2	21·7	21·4
7 – 7½	24·9	20·8	22·7
7½ – 8	26·1	21·4	25·6
8 – 8½	26·4	25·3	25·6
8½ – 9	27·2	25·2	27·2

Sown	...	November 1st, 1909
Harvested	...	March 14th, 1910
Area of crop which was weighed		50 sq. ft.
Weight of dry matter	seed ...	3·69 lbs.
	straw, &c. ...	5·60 „
	Total ...	9·29 „
Dry matter per sq. ft. ...	...	·186 „

LBS. WATER IN UNIT COLUMN.

Initial ...	188·9
Rain ·22″ ...	1·1
	190·0
Direct evaporation	17·7
Remaining at harvest	120·0
Transpired	52·3
	190·0
Ratio ...	$\frac{52·3}{·186} = 282$

STATEMENT No. XVII.

Linseed, Pusa, 1909-10.

Pounds of Water in Soil per Cub. ft.

Depth ft.	Manured. Initial, 21-11-09.	Harvest, 22-3-10.	21-4-10.	Unmanured. Initial, 21-11-09.	Harvest, 31-3-10.	30-4-10.
0 – ½	14·2	2·9	1·8	11·5	2·2	2·7
½ – 1	15·6	4·4	6·0	13·8	5.7	7·0
1 – 1½	16·9	5·0	7·9	14·4	7·1	8·1
1½ – 2	15·0	5 7	5·9	12 5	6·7	6·5
2 – 2½	13·9	6·5	6 0	14 9	6·0	6·5
2½ – 3	15·7	7·5	6·5	15·8	6·6	6 6
3 – 3½	17·5	8·8	8 0	19 6	8·3	7·6
3½ – 4	19·1	9·1	7·5	21·7	9·4	9·0
4 – 4½	19.6	9·7	8·2	19 3	14·7	14 4
4½ – 5	21·6	13·8	12·7	23·5	12·8	11·3
5 – 5½	23·1	11·6	9·6	23 5	16 4	14·2
5½ – 6	23 8	13·1	11·1	23·7	18·4	17 2
6 – 6½	25 7	17·8	16·3	24·4	21·6	20·7
6½ – 7	24·7	21·3	21·9	23·5	22·0	22·0
7 – 7½	23·5	22·2	22·4	24·5	22·6	22·4
7½ – 8	24·4	23·4	23·6	25·5	23 0	22·3
8 – 8½	25 5	23·2	22·5	25·5	25·0	23·4
8½ – 9	25·5	24·4	25·7	25·7	26·6	24·2

Sown	November 1st, 1909.	November 1st, 1909.
Harvested	March 22nd, 1910.	March 30th, 1910.
Area of crop which was weighed ..	60 sq. ft.	60 sq. ft.
Weight of dry matter { seed... .	·91 lbs.	1 0 lbs.
Weight of dry matter { straw ...	2·01 ,,	1·75 ,,
Weight of dry matter { chaff ..	·31 ,,	·75 ,,
Total ...	3·23 ,,	3·20 ,,
Dry matter per sq. ft.	·054 ,,	·053 ,,

Lbs. water in unit column.

Initial . ..	182·6	181·6
Rain · 22″ ...	1·1	1·1
	183·7	182·7
Direct evaporation	17·7	17·7
Remaining at harvest	115·2	127·6
Transpired	50·8	37·4
	183·7	182·7
Ratio	$\frac{50·8}{·054} = 940$	$\frac{37·4}{·053} =$

STATEMENT No. XVIII.

MUSTARD, PUSA, 1909-10.

Depth ft.	Pounds of Water in Soil per Cub. Ft.					
	Manured.			Unmanured.		
	Initial, 22-11-09.	Harvest, 7-3-10.	7-4-10.	Initial, 23-11-09.	Harvest, 9-3-10.	10-4-10.
0 — ½	14·6	7·5	6·6	11·7	4·9	4·3
½—1	15·8	10·7	9·2	13·0	7·7	9·9
1 —1½	15·1	13·4	7·8	13·9	9·3	11·4
1½—2	17·2	12·3	10·2	12·9	8·6	7·5
2 —2½	15·6	9·4	7·8	15·9	11·1	9·6
2½—3	16·0	8·9	7·3	17·8	11·1	10·5
3 —3½	18·0	10·2	8·5	18·5	10·7	9·7
3½—4	19·8	10·4	8·7	21·1	13·9	12·5
4 —4½	20·3	10·0	8·4	22·6	15·6	12·3
4½—5	23·1	11·7	11·4	22·0	15·8	11·9
5 —5½	22·6	16·5	14·4	21·7	11·2	12·7
5½—6	26·2	16·1	13·5	25·0	11·4	15·3
6 —6½	25·2	19·7	18·4	23·8	12·3	17·3
6½—7	23·5	20·3	21·9	23·4	22·4	21·4
7 —7½	24·1	21·6	22·5	24·4	23·7	23·2
7½—8	24·5	21·6	24·0	24·4	24·6	23·6
8 —8½	25·4	23·8	22·9	24·7	25·3	24·0
8½—9	26·4	25·3	25·8	25·9	25·0	24·6

Sown	...	November 1st, 1909	November 1st, 1909
Harvested	...	March 7th, 1910.	March 9th, 1910.
Area of crop which was weighed		60 sq. ft.	60 sq. ft.
Weight of dry matter	seed	·88 lbs.	·90 lbs.
	straw	2·84 „	2·77 „
	Total	3·72 „	3·67 „
Dry matter per sq. ft.		·062 „	·061 „

LBS. WATER IN UNIT COLUMN.

Initial	186·7	182·8
Rain = ·16″	·8	·8
	187·5	183·6
Direct evaporation	14·7	14·7
Remaining at harvest	134·7	139·8
Transpired	38·1	29·1
	187·5	183·6
Ratio	$\frac{38·1}{·062} = 614$	$\frac{29·1}{·061} = 477$

STATEMENT No. XIX.

Wheat, Cawnpore, 1908-9.

Pounds of Water in Soil per Cub. Ft.

Depth ft.	Initial.	Wheat plot A, harvest, 16-4-09.	Fallow plot D, 23-4-09.	Initial.	Wheat plot C, harvest, 19-4-09.	Fallow plot B, 22-4-09.
0 – ½	12·2	2·6	16·6*	18·1	4·5	10·4*
½ – 1	16·7	5·1	9·2	18·7	4·5	5·8
1 – 1½	15·9	6·0	9·8	21·6	7·7	7·1
1½ – 2	14·9	7·2	14·1	22·6	9·5	9·1
2 – 2½	16·5	7·6	11·9	24·4	10·2	9·6
2½ – 3	14·2	8·0	13·3	23·7	10·3	9·9
3 – 3½	17·8	9·1	13·0	25·2	12·2	10·5
3½ – 4	16·8	9·3	13·0	24·6	12·8	11·4
4 – 4½	18·5	8·8	11·8	25·0	13·2	9·5
4½ – 5	19·5	9·6	9·7	22·4	13·1	10·1
5 – 5½	18·7	9·5	12·0	25·1	13·8	11·6
5½ – 6	20·4	15·5	14·2	22·9	16·1	14·7
6 – 6½	23·0	15·0	15·6	23·5	16·6	16·4
6½ – 7	24·4	15·7	15·7	24·1	16·8	16·5
7 – 7½	26·5	22·2	16·3	27·1	19·0	21·7
7½ – 8	27·8	25·2	18·7	27·3	23·1	25·4
8 – 8½	30·4	22·0	19·4	31·4	25·9	24·8
8½ – 9	31·4	21·5	22·8	30.3	28·0	24·3

	A.	*C.*
Dry matter per sq. ft.	·117 lbs.	·110 lbs.

Lbs. water in unit column.

	A	C
Initial	182·8	219·0
Rain = ·25"	1·3	1·3
Irrigation	27·1	27·9
	211·2	248·2
Direct evaporation	49·6	64·6
Remaining at harvest ...	109·9	128·6
Transpired	51·7	55·0
	211·2	248·2
Ratio ...	$\frac{51·7}{·117} = 442$	$\frac{55·0}{·110} = 500$

* Rain fell on both these plots before they could be sampled.

STATEMENT No. XX.

WHEAT, CAWNPORE, 1909-10.

POUNDS OF WATER IN SOIL PER CUB. FT.

Depth ft.	Plot B, Wheat.		Plot A, Fallow.		Plot D, Wheat		Plot C, Fallow	
	Initial, 1-12-09.	Harvest, 9-4-10.	Initial, 29-11-09.	4-4-10.	Initial, 2-12-09.	Harvest, 7-4-10.	Initial, 30-11-09.	5-4-10.
0 – ½	5·2	2·0	8·3	5·6	6·3	2·5	7·4	4·3
½–1	10·7	5·5	12·4	8·9	10·9	5·8	11·0	8·8
1 –1½	12·5	5·5	14·1	10·5	13·7	7·4	12·8	10·8
1½–2	14·0	5·4	14·6	11·4	15·0	7·2	14·8	13·8
2 –2½	14·3	4·6	15·3	13·5	14·4	6·2	15·4	16·3
2½–3	14·9	4·9	13·0	13·0	14·0	6·0	14·8	15·8
3 –3½	14·2	5·6	12·6	10·0	13·3	6·8	15·1	19·3
3½–4	14·5	5·8	12·8	11·0	13·5	7·8	14·9	19·0
4 –4½	12·9	6·0	13·0	10·4	13·7	7·8	17·4	17·3
4½–5	12·8	6·8	14·4	14·0	12·0	9·7	16·2	16·5
5 –5½	15·2	10·1	15·4	15·4	13·3	11·0	17·0	14·1
5½–6	16·9	11·5	16·6	14·1	15·2	12·5	16·2	15·0
6 –6½	18·5	14·7	17·9	17·5	15·5	14·5	17·8	17·3
6½–7	20·8	16·1	21·2	19·8	16·3	14·6	19·4	16·2
7 –7½	24·5	18·0	26·0	23·3	18·0	17·1	20·3	19·6
7½–8	26·1	24·8	29·2	24·7	20·7	20·7	26·3	22·7
8 –8½	26·9	21·1	28·4	25·6	24·7	22·8	26·9	23·4
8½–9	26·5	16·9	29·0	26·5	23·0	21·8	27·7	24·4

	B.	*D.*
Dry matter per sq. ft.	·1615 lbs.	·1588 lbs.

LBS. WATER IN UNIT COLUMNS.

Initial	150·2	136·7
Rain = 1·81″	9·4	9·4
Irrigation	26·0	23·7
	185·6	169·8
Direct evaporation	27·4	20·8
Remaining at harvest	92·6	101·1
Transpired	65·6	47·9
	185·6	169·8
Ratio	$\frac{65·6}{·161} = 407$	$\frac{47·9}{·159} = 302$

CHART VIII.

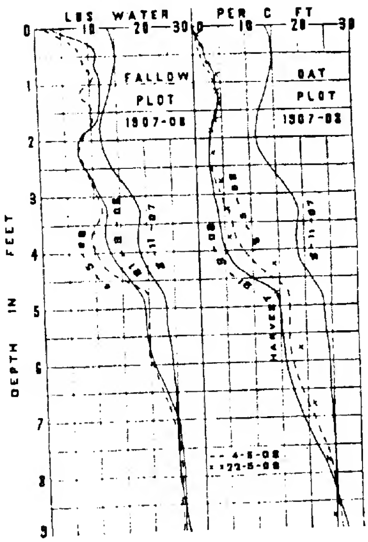


CHART XIV.

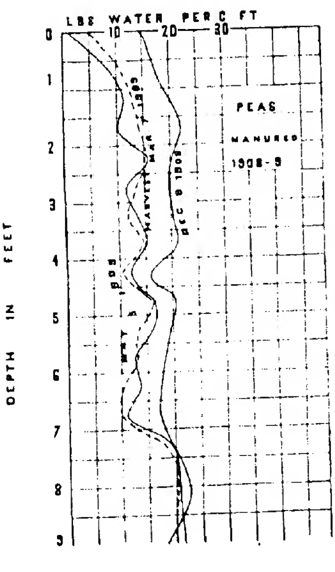


CHART XIII.

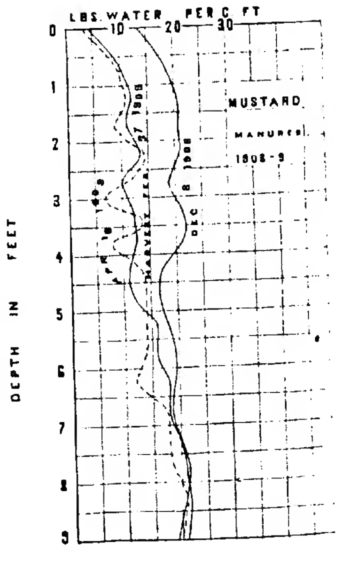


CHART XV.

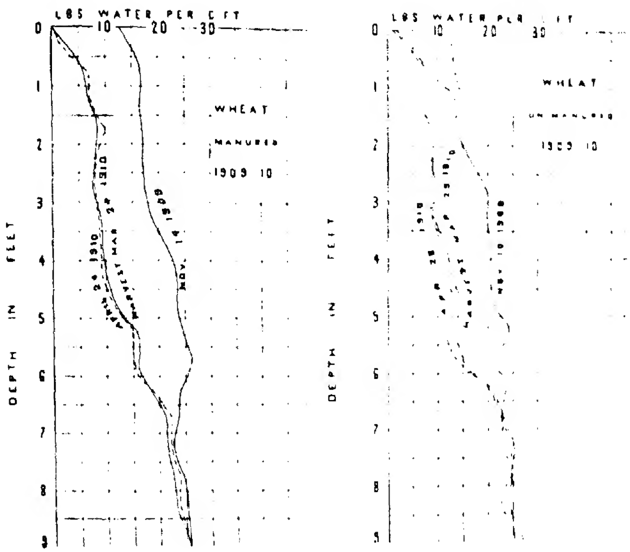


CHART XVI.

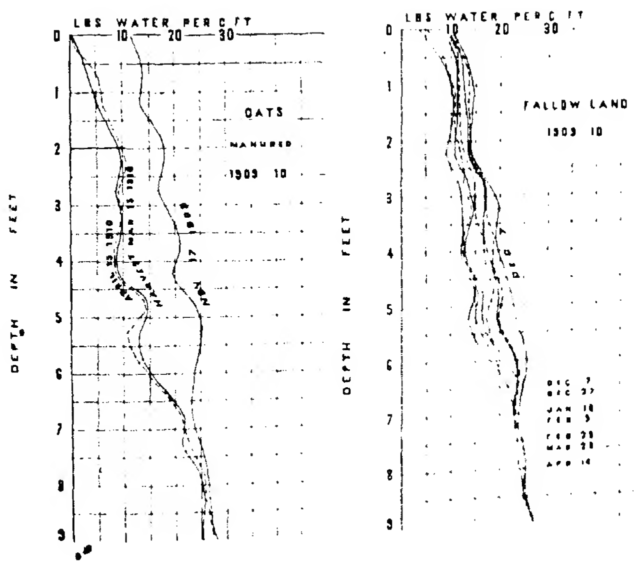


CHART XVII.

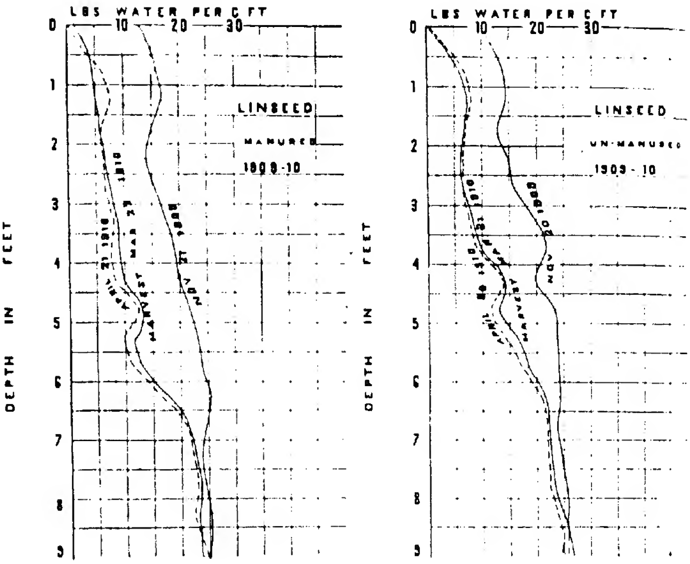
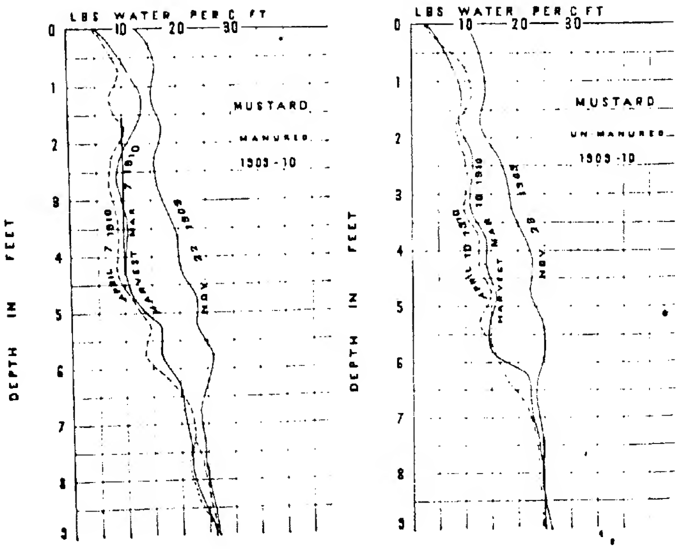


CHART XVIII.



Another fact brought out by the decrease of water concentration through crop agency is that the decrease is more or less constant throughout 5 or 6 feet. The general idea is that, although some roots extend through a number of feet, the greater part of the root system develops in the first foot or so of the soil. As a matter of fact we are not concerned here with either the total length of the root system or with the number of roots, but purely with the organs which assimilate the water, and the question one would like to answer is what is *their* distribution and how far apart are they? I trust this does not read as though it is suggested that such organs take up fixed positions in the soil; it is, of course, perfectly well understood that they have a temporary existence, and that as each fulfils its allotted task and dies off, it is followed by a new one further on. But they must be distributed in some systematic manner, and judging by the magnitude of the decreases of water in succeeding feet of soil they seem to have been nearly as numerous in the fifth and sixth feet at Pusa as in the first. In the irrigated soil at Cawnpore the case is nearly the same, though after allowing for the irrigation water, there must have been more water assimilated in the first and second feet than in the fourth and fifth feet.

The amount of Water transpired. As explained in the Introduction, the object of these field tests was not limited to obtaining information in regard to decreases of soil moisture due to crops, and the extent in the sub-soil to which such decreases occur, but also to try to estimate the amount of water transpired, and to compare this with the weight of crop grown, in order to ascertain whether this ratio agreed substantially with that which has been obtained by pot-culture methods.

Now it is not feasible to estimate directly the quantity of water which is brought to the surface of the land and evaporated or the quantity transpired by crops. I considered at one time whether it would be possible to so enclose a portion of a crop that, if air were passed freely over it, the increase of moisture in this air could be determined with a sufficient degree of precision.

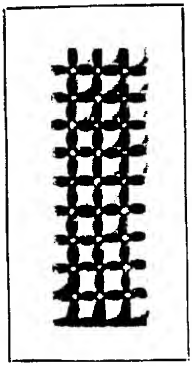
and it became evident that such a method would be quite impracticable. Only one of a number of difficulties need be here stated. Suppose that a part of a crop were enclosed in an apparatus which would cause no abnormal solar or radiation effects and air were uniformly passed over the crop, the error in determining such differences of atmospheric humidity, whether measured daily or half-daily or for any other period of time, would be too great to admit of the necessary precision. It must be recollected in this respect that ordinary air must be employed, containing, say, 75 per cent. humidity, and that if, while such air were passing over the crop, the transpired water raised the humidity to say 85 per cent., changed conditions would be thereby introduced, which could not fail to affect the rate of transpiration, and yet even with so small a difference of humidity between the air before and after passing over the crop, it would be impossible to determine with sufficient precision the respective amounts of water. Such a method of directly estimating the amount of water transpired by a crop is then for these reasons alone impracticable. Numerous other difficulties also arise, some of which are equally weighty.

It is, however, possible to employ an *indirect* method, provided it is allowed to be a sound one.

In Memoir No. 6 and *Nature*, Jan. 14th, 1909, I gave reasons which were based on arguments used by Lyman Briggs,* for assuming that, if a series of soil moisture determinations are made throughout succeeding strata of soil, and it is found that no change of concentration occurs during the period of observation below a certain depth (provided also that the sub-soil water is at least some feet below this stratum), it may be held that no material amount of movement of soil moisture has occurred from this depth during the period. The data quoted in that memoir dealt with changes of soil moisture in fallow land during dry weather, but the arguments there used are of quite general application. It is perhaps necessary to recapitulate them here in order to show their connection with the experiments on

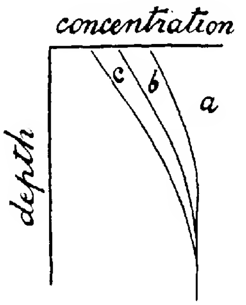
* Bull. 10, Division of Soils, U. S. Dept. Agric.

crops which are now under review. Briggs assumed that the water in soils (*i.e.*, the liquid water) is retained, after drainage has ceased, between soil particles in the manner indicated in the marginal figure. It is, of course, well understood that a mass of soil does not consist simply of particles arranged in the simple geometric manner that the spheres occupy in the illustration, much less that they are spherical or all of one size: it is indeed probable, though the fact has not been demonstrated, that collections or aggregates of soil particles occur, which aggregates owe their existence to the surface tension of the water between them. But whatever the real arrangement of particles in the soil, the movements of water after drainage has ceased must depend on changes in the quantity of water between neighbouring particles, which produce differences in surface energy. And Briggs pointed out that, if at any point water is removed from between two particles, this will occasion a change in the curvature of the surface of the water remaining, which will cause a flow of water from between the neighbouring particles, and this motion will be communicated throughout the whole mass. This argument has been generally accepted as sound.



Founded on this the further argument follows that, supposing water to be abstracted from any part of such a system, and a series of moisture determinations be made across the direction of the flow of water before the effect of this water movement has had time to cause a *measurable* effect at the further end of the system, a decrease of water concentration will be found throughout, though the magnitude of this decrease will diminish towards the further end of the system. If now a second series of such determinations of water-concentration be made after a time interval insufficient to admit of a *measurable* effect at the further end of the system, the concentration will be found to have further

decreased in each succeeding plane. In fact the periodical concentrations may be illustrated by the diagram below. In it the curves *b* and *c* represent the subsequent concentrations of water and are drawn cutting the curve *a* of initial concentration. Very probably they meet it asymptotically, but this fact



would not materially affect the question. This movement of water *must* be accompanied by a decrease of concentration, and hence it follows that the area between the curves *a* and *b* would express, within the limits of experimental error, the total quantity of water which had flowed through this part of the system during the period of observation. There are experimental difficulties in making the series of water determinations with precision, the changes in concentration in that part of the system which is represented by the lower end of the curves being particularly difficult to ascertain, but this does not affect the principles involved.

There is I think a popular belief that, so soon as water commences to evaporate, say, at the surface of land there is an upward movement of water towards the surface from all depths. On the contrary, the movement is not immediately communicated throughout. Far from such being the case, considerable periods of time may be required for such a movement of water which originates (in the example just mentioned) at the surface, to be communicated through a number of feet of soil. This will perhaps be best demonstrated by the following line of argument. Suppose after a period of dry weather a fall of rain, say 1".

occurs, succeeded by fine weather. This 1″ of water will soak into the upper soil and a series of water determinations would show its distribution. Suppose it were found to be distributed through the first 6″. Now the difference in water concentration existing between the first 6″ and the next would cause this water to move downwards, which motion would continue in the downward direction until the surface energy of the water between all particles became equal. Such a process would take time, but changes would be *perceptible* for several days. On the other hand, however, fine weather is supposed to have set in and this necessarily occasions *evaporation*, accompanied by a movement of water towards the surface. We have then water moving *at the same time* in both directions. The case may be illustrated graphically as in the four small charts.

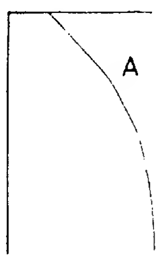


FIG. 1.

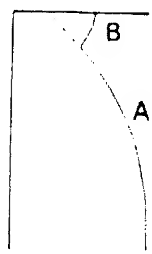


FIG. 2.

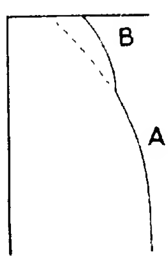


FIG. 3.

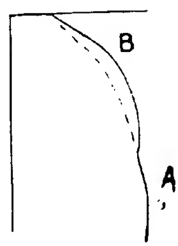


FIG. 4.

The curve A in Fig. 1 represents the initial concentration of water; in Fig. 2 the added curve B represents the first effect of the rainfall whilst the Figs. 3 & 4 illustrate how this "wave"

of moisture spreads itself downwards, whilst concurrently evaporation at the surface reduces it there, and the "height" of the wave constantly diminishes. An example of this was recorded in 1908 and the data are set out in the Statement No. XXI. On August 12th after a long "break" in the rains, 1·34″ of rain fell. A moisture record had been kept in a plot of fallow land, and the concentration of water on August 6th is shown in the first column. After the rainfall, moisture determinations were made on 13th, 15th, 17th and 19th. After the 12th the following rain fell: ·02″ on 17th and ·06″ on 19th.

STATEMENT No. XXI.

SHOWING THE EFFECT OF A "WAVE" OF DRAINAGE.

DEPTH.	6-8-08.	13-8-08.	15-8-08.	17-8-08.	19-8-08.
0″–3″	6·75	14·42	10·75	8·60	6·62
3″–6″	9·98	13·94	11·55	10·83	10·42
6″–9″	11·72	14·18	12·28	11·27	10·42
9″–1′	11·23	11·51	12·08	10·42	12·56
1′0″–1′3″	10·30	9·45	10·95	9·13	10·18
1′3″–1′6″	8·20	7·03	8·38	8·89	10·14
1′6″–1′9″	8·69	7·31	10·50	6·46	8·12
1′9″–2′0″	7·23	5·29	7·11	7·35	7·11

Thus the first day after the rain, the water had spread itself through about 9″ of soil: two days later the moisture had increased in the next lower 3″ but had decreased again throughout the upper 9″: on 17th a further decrease was noticeable in the top 3″, but other changes had become too small to estimate: after this date further changes could not be determined though they must have been still in progress. Similar changes must occur after every irrigation. The same must constantly occur especially in countries which have a well distributed rainfall. It is known that drainage does not cease in, at least many, soils at 6 ft. for days, and judging by the difference of time required for drainage to cease in drain-gauges at 3 ft. and at 6 ft. respectively, at 10 or 15 ft. from the surface drainage must

continue for a week or more after rain ceases; but in the event of fine weather, water is nevertheless evaporating concurrently at the surface, and there is necessarily a movement through some part of the soil towards the surface, *i.e.*, it must, in such countries, be constantly the case that in one and the same soil water is, in the upper part moving towards the surface, in the lower part moving downwards.

These examples show how readily it may be that soil moisture, even in the protracted periods of dry weather which occur in India, is not necessarily moving through all distances in the soil simply because it is known to be moving through a certain part or stratum of it.

In order to fix ideas regarding the measurement of the total quantity of water which has moved through a soil in a given time, take the case of the Pusa soil, fallow, 1909-10, in which the series of measurements of water concentration were made and which are illustrated in Chart No. XVI. The rainfall of the period was ·22" which was obviously insufficient to affect the argument we are considering. This record shows that there was a gradual decrease of soil moisture in the upper 6½ft. of soil, but that no measurable decrease occurred below 6½ft. It has been argued (*Nature*, Augt. 8th, 1909) that because no decrease was observed below this depth, is no proof that there was no upward movement; but since any upward movement is necessarily accompanied by a decrease of concentration, this fact is a proof that the amount of upward movement below 7 ft. is extremely small. The real defect lies not in the argument, but rather in the accuracy of the measurement. If the latter were more exact, there would be found at the end of each succeeding period of time a decrease in a lower stratum than had been found to be the case at the preceding date. The changes in the upper 4 or 5 ft. of this soil are so great that they are readily measurable by our method; this is a light soil for the most part through which water can move freely. But below this in the clay the movement of water is necessarily slow, changes of concentration are therefore small, and hence the difficulty of determining them.

And what applies to fallow land applies likewise to the soil from which water is being abstracted by plant roots. The examples of this effect which have been quoted show how, at harvest time, a greater decrease of soil moisture has occurred under the influence of a crop, and that this effect is easily measurable to one or to two feet deeper than where the land is merely evaporating water at the surface; but the *nature* of the changes are the same. In some cases there is a doubt whether the moisture determinations were carried as deep as might have been wished, but since the inaccuracies of the method have been so fully admitted, it will be sufficient to say that the observed change of concentration of moisture where a crop is grown should correspond approximately to the total amount of water which has been transpired by the plant and evaporated directly from the soil.

Calculations to this end for each of the crops have, therefore, been made in order to compare these quantities with those estimated by pot-culture methods.

It will be readily appreciated that whilst the total change of water-content in the unit column of soil can be simply estimated from the observed changes of concentration, such estimate includes the water which has been withdrawn from the soil by both agencies, transpiration and evaporation, whilst we desire information regarding the former as distinct from the latter. Although there is no method for the direct experimental estimation of the quantity evaporated, an attempt has been made to form at least a conception of it.

This estimate is made as follows: While the crop is young and transpiring only nominal amounts of water, the *evaporation* must be very similar to what would occur in the same soil if fallow. After this period, however, the crop shoots rapidly and covers the ground, either entirely or in a great measure. Now there are three reasons for assuming that this must necessarily very largely restrict direct evaporation: (*i*) since the plant is constantly transpiring large amounts of water, the atmosphere in between the leaves and stems must be highly saturated with water

vapour; (*ii*) the stems and leaves of the plants being close together, air movements are largely restricted, so that the highly humid atmosphere among the plants is held in position as a covering over the soil, and would necessarily reduce evaporation below what would occur into a dry atmosphere; (*iii*) the plant reduces the concentration of moisture in the top most soil, and since a relatively dry soil will evaporate less water per unit time than a moister one, this effect of the plant will also tend to reduce direct evaporation. Some very interesting information in respect of the humidity of the atmosphere within a crop was published by Yapp* whose experiments demonstrate the fact that this part of the atmosphere is very highly charged with water vapour.

Data which have been obtained during three years by means of the drain-gauges, two of which are fallow and two cropped, indicate that where a good *rabi* crop is growing, the amount of water which simply evaporates from the soil, as distinct from that transpired, is only about one-half of what it would be if the land were fallow. For the purpose of estimating the amount of water transpired by the crops, this proportion has therefore been adopted. The data which have been utilised are all set out in the lower part of the Statements Nos. VIII to XX. After details regarding the weight of the crop, a "balance sheet" has been made to account for the water involved in each case. Thus we have the water in the soil at sowing time; this is styled the "initial" water. If the rainfall (and irrigation in the Cawnpore experiments) be added, the sum is the total water involved. On the other side of the account we have its disposal, which includes (i) *direct evaporation*; (ii) the *water remaining in the soil at harvest*; (iii) that *transpired*, which is obviously obtained by difference. This quantity may then be divided by the weight of the crop, and this ratio compared with that obtained in the pot-culture house. The results of such calculations are here collected in Statement No. XXII.

* Yapp, Ann. of Bot., 1909, p. 275, et seq.

STATEMENT No. XXII.

Transpiration ratios obtained by (*a*) pot-cultures and (*b*) field method.

Crop.	By Pot-culture.	By field method.				
		Pusa.			Cawnpore.	
		1907-08.	1908-09.	1909-10.	1908-09.	1909-10.
Oats ...	400 – 500	411	230 : 331	282	...	
Wheat ...	450 – 650	...	415	313 : 237	442 : 500	407 : 302
Barley ...	450 – 650		341 : 430	...	...	
Peas ...	600 – 800		505 : 314			
Linseed ...	600 – 1000		718 : 693	940 : 706		
Mustard ...	400 – 550	...	298 : 471	614 : 477		

The pot-culture ratios quoted are those for small and large crops respectively, but since the crops grown in the field were in nearly all cases heavy ones (the cereals were all equal to or greater than 5,000 lbs. per acre), the field ratios should be comparable rather with the lower than with the higher pot-culture ratio. An examination of these ratios admits of the following conclusions :—

(i) They vary among themselves, but not to a greater degree than has been found in pot-culture experiments ;

(ii) the comparison between the ratios obtained by the two methods shows that, for oats it was generally less in the field, for wheat it was low in three out of seven tests, for barley about normal, for the other three crops the field ratios were frequently higher than the pot-culture ratio. If the comparison of the whole of the tests be made irrespective of crop, there are nearly as many field ratios higher than, as less than, the pot-culture ratio.

Looked at as a whole the nett result of this part of the investigation has been to yield ratios which certainly support the pot-culture work as well as could be expected of the

method. There are two points which may be here suitably referred to. (i) The pot-cultures have shown uniformly that the larger the mass of earth in which plants grew, the lower became the ratio, and consequently, unless in our pot-culture tests the quantities of soil employed have been sufficient to produce a maximum effect in this respect, the transpiration-ratio of crops growing in the field, where the mass of soil at the disposal of the crops is so very much larger than that employed in our largest pot culture jars, might be expected to be lower than that obtained by the pot-culture method. Thus this factor must be assumed to be one of the causes tending to low field ratios. (ii) Some water would move upwards undetermined by the method employed. An instance which is of considerable value in showing how small this is may be here quoted.

In 1908, at the end of a very weak monsoon, some land which had borne grass was cleared, and prepared for "cold weather" sowings. Only very trifling amounts of drainage had occurred at 3 ft. and 6 ft. from the gauges during the monsoon and the grass had not only assimilated the rainfall, but, as the record showed (see adjoining Statement No. XXIII), it had depleted this land of a large amount of its moisture; the defect being from one-half to three-quarters in the upper 6 ft., *below which the concentration of water was about normal*. Seed sown on this soil in October germinated very badly, and the subsequent growth was so poor that no weight of the crop was kept, but the moisture present in February was estimated and is included in the Statement. If as much as 10 pounds of water per unit column of soil had come up from below 9 ft., it should have been able to support a crop of (say) 600 or 700 lbs. of dry matter per acre, whereas the *one* which actually struggled for existence was far below even this small figure. Better evidence of the inability of the large stores of water contained in the soil *below the root range* to serve a crop could hardly be provided, and it can only be explained on the assumption that this water is *moving* extremely slowly.

Statement No. XXIII *showing concentration of water in Pusa soil* (a) *under normal condition,* (b) *after grass coupled with weak monsoon.*

Depth ft.	Pounds of Water per Cub. Ft.		
	(a)	(b) 14-10-08.	Barley plot. 1-2-09.
0 – ½	14·2	6·5	1·8
½ – 1	15·6	9·3	4·8
1 – 1½	16·9	8·4	5·8
1½ – 2	15·0	7·7	6·7
2 – 2½	13·9	5·8	4·8
2½ – 3	15·7	6·9	4·3
3 – 3½	17·5	5·1	4·9
3½ – 4	19·1	5·1	5·5
4 – 4½	19·6	4·8	5·1
4½ – 5	21·6	7·3	7·9
5 – 5½	23·1	...	11·1
5½ – 6	23·8	6·3	10·5
6 – 6½	25·7	...	14·9
6½ – 7	24·7	22·6	20·2
7 – 7½	23·5	...	23·3
7½ – 8	24·4	25·0	21·9
8 – 8½	25·5	...	25·2
8½ – 9	25·5	25·8	26·5

Changes of concentration of water in the soil subsequent to harvest.—The fact that a certain amount of water will move upwards undetermined by the change in moisture concentrations between two dates, has been referred to, but it was argued that it must be only small. In order to try to form a conception of its amount the following tests were made. It has been demonstrated that the concentration of water is generally decreased to a greater degree where a crop has grown than where the soil is merely left fallow. Thus at harvest throughout several feet of soil there is a deficiency of water. What is to be anticipated after removal of the agent, that is, the crop, which has created such deficiency? Will not this soil stratum, in which the deficiency has been created, tend to hold any water that is moving upwards so as to resume the higher degree of moistness which it would have contained had it been merely fallow?

In order to test this question, determinations of the moisture in the soil a month or six weeks after harvest have been made in each year, and the data relating to these are included in the Statements Nos. VIII and XIII to XVIII. In 1908, after harvesting

the oat crop, moisture determinations were made five and seven weeks respectively after harvest: during the former period there was no rain, but ·53" fell on May 7th, that is, at the commencement of the second period. This fall which is equivalent to 2·8 lbs. per sq. ft. is unimportant in respect of the matter we are considering, since it could not appreciably affect the soil moisture below the first foot. A comparison of the concentration of water in the several feet, more especially between 2 and 7 ft. deep, shows that there was a distinct increase of soil moisture after harvest, which was accompanied by a decrease below 8 ft. In 1909 about two months after harvest, two tests were made in the mustard and peas plots respectively (Statements Nos. XIII, XIV). The rain which fell on the former plot amounted to ·51", on the latter 3·47". The former is of no consequence. The latter included two principal falls, namely, 1·15" on April 18th and ·91" on April 29th which was 7 days prior to the second determination of moisture. Although the effect of the 1·15" would have practically disappeared before the determination of May 5th, that of the latter would hardly have passed off, though it could only materially affect the first foot. As a matter of fact on May 5th the first 6" was distinctly moister than on 7th March. Neither of these records possess the same regularity that characterised the first test in 1908. In 1910 tests were taken a month after harvest in all the seven plots. The rainfalls of the several periods were of no consequence. Here the results possess considerable regularity. As the curves show, there was an increase in the 9th and 8th feet in four plots, a decrease in one plot and no marked change in two: above the 8th foot there was a general decrease. As a matter of fact, the test is by no means a very delicate one for the end in view. Any such remoistening must necessarily be the difference between the water received from below and that which is evaporating, and assuming that the soil does tend to hold water in the manner suggested, the nett augmentation of water will presumably depend in a great measure on the degree to which the crop desiccates the sub-soil beyond what would *occur if no crop were*

there; in other words, if, in the sub-soil at harvest, there is a *large* deficiency of water due to the crop, the tendency subsequent to harvest would presumably be for a relatively large accumulation of water in this part of the sub-soil, whilst if the effect of the crop is only to cause a small deficiency, the subsequent accumulation of water would likewise be only small. Thus, of all the crops, the oats of 1907-8 caused the greatest deficiency, namely, about 40 lbs. in the unit column; among the crops of 1909-10 wheat (manured) caused a deficiency of 26 lbs., oats (manured) caused one of 27 lbs. and the manured linseed one of 32 lbs. of water; of these the first three were followed by a subsequent accumulation of water in the sub-soil after removal of the crops, whilst the last was followed by a further decrease. The other crops created only small deficiencies of water and no accumulation was perceptible in them subsequent to harvest. The fact, however, of it being so difficult to detect this change, which on theoretical grounds should occur, is a further indication of how small must be the amount of water which is moving upwards during dry weather in this particular soil from below 8 or 9 ft.

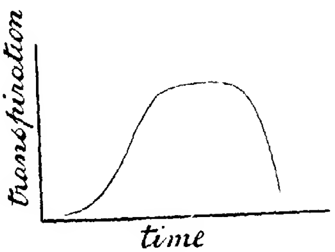
In the foregoing paragraphs evidence has been adduced to show that the quantity of water which rose in the Pusa soil undetected must have been less than 10 lbs. per sq. ft. of cross section. But it must be recollected that there is nothing to show that the quantity was as much as even one pound. The somewhat lower transpiration ratios found for some of the field crops would be as easily accounted for by the greater mass of soil as by an undetected quantity of water.

The quantity of water present within the root range.—The available information in respect of root development is admittedly very limited, but crop roots have been traced through a number of feet.

Assuming that the decrease of soil moisture as exhibited by the Charts Nos. VIII & XIII—XVIII indicate the active root range, this amounts to 7 or 8 ft. Now the amount of water

present in the unit column of soil at sowing time has been found to be from 150 to 200 lbs. in the soils at Pusa and Cawnpore, or deducting 25 lbs. for the 9th foot of soil, it is evident that the total quantity of water present is from two to four times as much as heavy crops require.

The daily requirement of water by a crop during the period of maximum assimilation. On page 178 of Memoir No. 8 it was pointed out that the greater part of the water required for the development of a crop is assimilated during a limited period. The curves deduced from the pot cultures are all similar in showing that there is a period of maximum transpiration, and neglecting the temporary effects of temperature and humidity, it may be represented by the curve shown below.



From the curves which have been obtained it is easy to calculate approximately the mean amount of water daily transpired during the period of greatest assimilation, and thence, on the assumption that this mean quantity is proportional to the weight of crop, to reduce the results of all experiments either to one common standard of crop-weight or to a limited number of such weights. Such a calculation would provide an indication of the amount of water required per day during the period of maximum assimilation by a crop of standard weight. The assumption that the weight of water transpired is proportional to the weight of crop we know to be not strictly the case, and hence to make the calculations indicated is not free from objection. Nevertheless the information obtained, although only approximately correct, is of interest in relation to what follows.

The following Statement No. XXIV exhibits the quantities of water so required.

STATEMENT No. XXIV.

Crop.		Standard weight. lbs.	Water required per sq. ft. of land per day. lbs.	Period during which maximum water requirement continues. Days.
Wheat	...	5,000	·7	40
Barley	..	5,000	·6	40
Oats	...	5,000	·6	40
Sarson	..	5,000	·6	40
Linseed	...	3,000	·8	30
Peas	..	5,000	1·0	30
Gram		5,000	1·1	40
Maize	...	5,000	·4	40

For the "standard weight," which naturally includes straw, leaves, etc., as well as grain, quantities have been taken which will be open to criticism because the weight of a "heavy" crop varies so much in different localities. The period also during which the major part of the water is transpired will also vary with the climate.

Factors regulating movement of water.—The field experiments which have been dealt with in the previous paragraphs have demonstrated four facts :—

(i) The quantity of water within the root range was far in excess, from two to four times as much, of that which heavy crops require.

(ii) That during growth a marked decrease of water concentration occurs through 7 or 8 ft. of soil, which coincides with the root range so far as we have information on the subject.

(iii) That after a normal monsoon the Pusa soil, if it has been fallow, can support a heavy cold weather crop without material additions of water ; on the other hand, the Cawnpore soil is unable to do so.

(iv) That if a soil like that at Pusa is largely depleted, *within* the root range, of its usual store of water, but contains *below* the root range a normal and large amount of water, the latter is practically of no use to the crop.

Now, these several facts, as well as each of the other features which have been dealt with, would be accounted for if the water supply through the soil to the plant were controlled under the influence of surface tension, by a law similar to that which governs the transmission of heat or the diffusion of salts. Doubtless the cases are not identical, and the movement of water through soils is probably not so simple. Nevertheless if the chief factors are the same, the quantity moving per unit time would vary, (i) directly as the difference of concentration of water at the two ends of the column, which difference might be styled "potential," (ii) inversely as the square of the distance, (iii) directly as the magnitude of some "constant" peculiar to each soil.

Thus in any one soil, the plant would receive more water per hour or day, the more water is present in the soil, and the shorter the distance through which the water has to travel.

The action of the root will be to lower the concentration of water in its immediate neighbourhood, and water will flow towards it horizontally as also from below. The following typical cases may now be considered.

(*a*) The soil contains abundance of water for the requirements of the root *within its length* and water moves freely through the soil. Then the root's requirement will be satisfied by a comparatively small lowering of the water concentration in the soil throughout the root length. Water will tend to move upward from below to increase again this reduced concentration, but as the distance below the root range increases, the quantity moving will rapidly diminish. Example, Pusa soil.

(*b*) The soil contains similarly large proportions of water, but water cannot move freely through the soil. The root would be served with a deficiency of water resulting in a small above-ground growth. It would be just as difficult for water to move from below. Example, Cawnpore soil.

(*c*) The soil, say a sandy one, contains too little water within the root range for a heavy crop, but water moves freely through it. Owing to low concentration the root would be served badly

with water within the root range and water would tend to move upwards, but as the concentration below the root fell and the distance through which the water would have to move increased, its quantity would fall off rapidly.

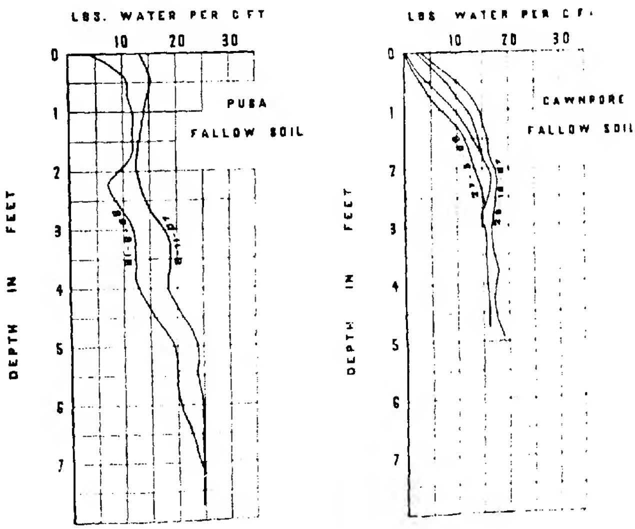
(*d*) The soil within the root range contains too little water for a heavy crop, but contains abundance one or two feet below the root system; water can move freely through the soil. Here the root would be served badly by the soil within its length owing to low concentration; from below the quantity of water moving per unit time would be small on account of the great distance through which it would have to pass to the root. Example, Barley crop on Pusa soil, 1908-09 (page 271).

In the foregoing it has been assumed that the roots are assimilating water throughout the whole length of the root-range at the same time. As a matter of fact but little is known about this matter. It may be that the assimilation proceeds largely inch by inch and foot by foot as the root system develops, resulting in each layer or stratum of soil being largely depleted of its water successively: or it may be that the root extension is so rapid that the reduction of concentration occurs more or less simultaneously in the whole column of soil. It may be mentioned, however, that in the drain gauges, roots come through the false bottoms at 3 ft. when the crop is quite young, and this has also occurred at Cawnpore in the six-foot gauges. Such evidence would indicate the second of the above suggestions as being nearer the truth. However this may be, the final state of the soil moisture corresponds with what would be expected if the quantity of water moving through a soil to a root system obeyed a law similar to the one which has been set out. There is a large and nearly uniform decrease of concentration in the upper 5 or 6 ft. of soil, below which the decrease becomes rapidly small.

The decreases of water in fallow land during dry weather also agree well both with the soil's ability to support vegetation as also with what a law such as that suggested would demand. The accompanying Chart XXV shows the concentration of water in fallow soil at Pusa and Cawnpore respectively in 1908. The

shape of the curves of the one is characteristically different from that of the other; that for the Cawnpore soil being much the steeper. Such a difference of shape would indicate the Cawnpore soil to be a worse "conductor" of soil moisture than the Pusa soil. If such were the case, the Cawnpore soil would lose less water into the atmosphere during dry weather: its water would also move to the plant root less readily. As already mentioned, the latter

CHART XXV.



feature would tend to the production of a smaller crop at Cawnpore than at Pusa, which is known to be the case.

It may be stated indeed as a general rule that among soils which are fairly homogeneous throughout the upper 7 or 8 ft., those which lose much water when fallow during dry weather will serve the crop's root system well with water; those on the other hand, which dry principally at the surface but lose on the whole but little water, will serve the crop badly and require either rain or irrigation.

CONCLUSIONS.

(i) The transpiration ratios obtained with other soils than that of Pusa show that the nature of the soil has no influence on the ratio, provided the water-supply in the soil does not fall below a certain concentration.

(ii) The concentration of water in the soil which is necessary for good development varies largely with the nature of the soil. Thus 10% in the Pusa soil is sufficient for the development of good plants though not the largest: in the Black Cotton soil 25% is too small for anything but the most meagre growth.

(iii) In the field, the action of the plant is to cause a marked decrease of concentration throughout a number of feet of soil.

(iv) This reduction of concentration was in the Pusa soil more or less uniform for about 5 or 6 ft. below which the change is smaller.

(v) A comparison of the observed decrease of water in a unit column of soil (after making an allowance for the water which evaporates directly from the soil into the air) with the weight of crops produced, yields a ratio closely approximating to that obtained by the pot-culture method.

(vi) Most of the water required by a crop is thus accounted for by the observed decrease of water within the root range. The amount of water which moves up from the sub-soil undetected is shown (page 271) to be necessarily small.

(vii) The soil within the root range is at harvest time frequently much more desiccated than it would be if it had been simply fallow. After the crop is removed there is a tendency for the water which moves up from below, to re-moisten this upper soil, but the process is certainly a very slow one.

(viii) The effect of a *kharif* (rains) crop in India will be in many cases the partial depletion of the water in the upper soil of the root range, whilst that in the soil below this stratum will be nearly or quite normal. If now such land be cultivated and sown with a *rabi* crop, the supply of water within

the root range will be defective, whilst that in the soil below is unable to assist the second crop, although the latter quantity is actually very large.

(ix) The whole of the facts which have been brought out by the experiments detailed in this memoir would be accounted for if the quantity of water which can move through a soil per unit time were dependent on the three factors, concentration, distance and physical character of the soil; temperature also no doubt has an important influence.

(x) There can be no doubt that if a laboratory method could be devised for the estimation of the soil's capacity for the "conduction" of water, such method would become of very great value to agriculture.

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